CYCLIALKYLATION OF BENZENE WITH ISOPRENE

By

WELDON MENNO HARMS

Bachelor of Science

Northwestern State College

Alva, Oklahoma

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Thesis Approved:

E. J. Eisenbraun
Thesis Adviser

O. C. Dermer

Horacio A. Mottola

L. Herbert Burnett

N. Durham
Dean of the Graduate College

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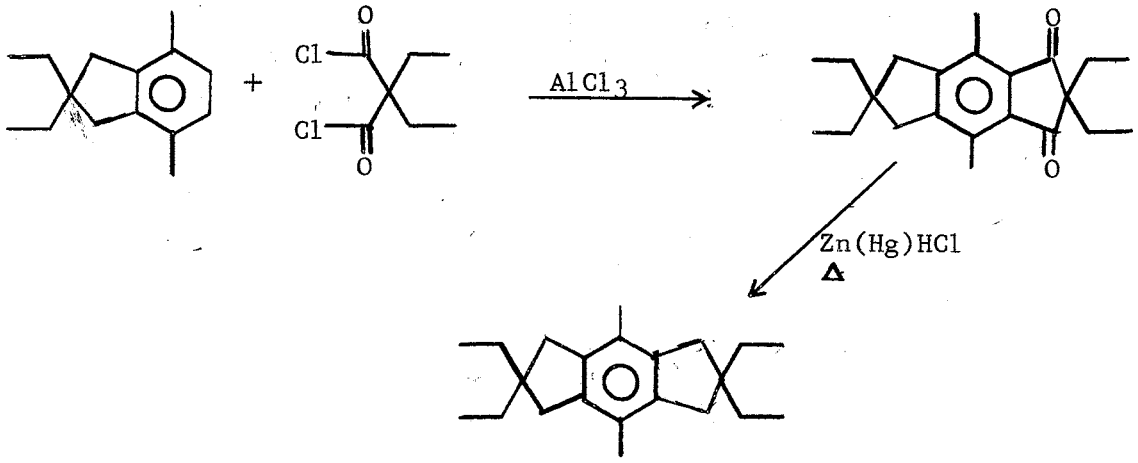
CHAPTER I

HISTORICAL

Alkylhydrindacenes have been obtained by several multi-step routes. Freund and Fleischer[1] in 1917 prepared 4,8-dimethyl-2,2,6,6-tetramethyl-s-hydrindacene as shown in Scheme I. Also reported were two isomeric diketones obtained from the reaction of diethylmalonyl dichloride with 2,2-diethylindan.

Scheme I



During the 1917-56 period fewer than twenty hydrindacenes or their ketone derivatives were reported. Activity in hydrindacene synthesis has sharply increased since that time and many of the important

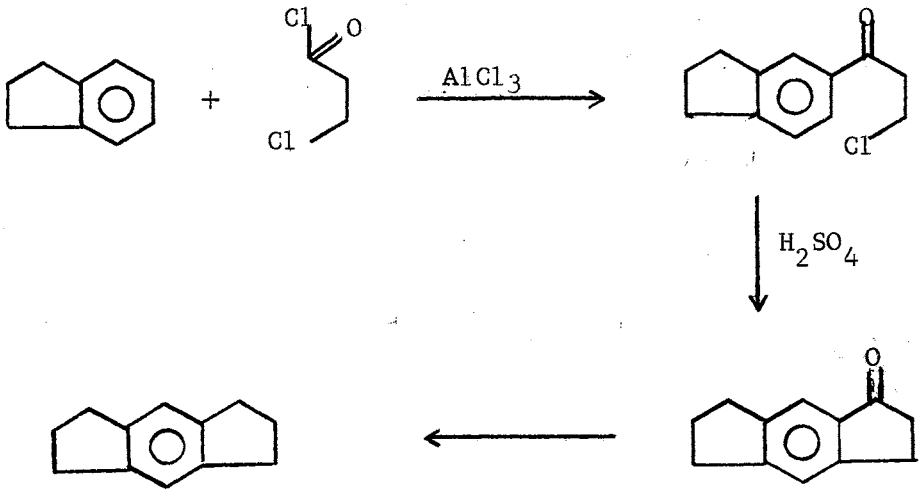
developments are summarized below.

Cyclialkylation is a term introduced by Bruson and Kroeger[2] to describe acid-catalyzed condensations of aromatic compounds and difunctional molecules such as dichlorides, diols, and dienes. In their paper, synthesis of a cyclopentanophenol (an indan) was reported. Indans have been shown to be precursors and intermediates in hydrindacene formation.[3,4]

The term cyclialkylation is now used to describe all electrophilic ring closures onto aromatic systems, including intramolecular ring closures of aryl-substituted compounds.[5]

One convenient synthesis of s-hydrindacene was reported by Arnold and Rondestvelt,[6] who cyclialkylated indan with 3-chloropropionyl chloride to s-hydrindacen-1-one. This ketone was reduced to the hydrocarbon (Scheme II). Later the cyclialkylation of various indans

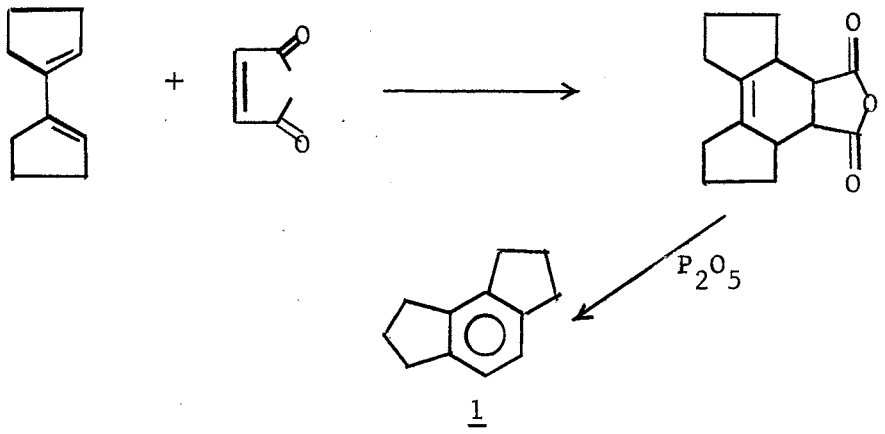
Scheme II



with 3-chloropropionyl chloride was patented as a process for the synthesis of hydrindacene musks.[7]

Russian workers synthesized as-hydrindacene (1) and several alkyl derivatives.[8] The method involves Diels-Alder addition of a maleic anhydride to bi-1-cyclopenten-1-yl followed by aromatization of the central nucleus (Scheme III).

Scheme III

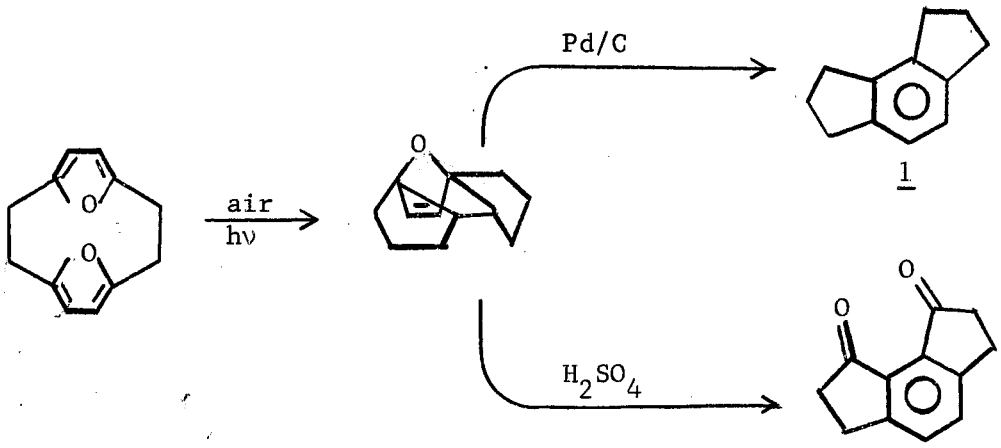


1

Wasserman and Doumaux[9] described the formation of 1 and its 1,8-dioxo derivative in a novel structure proof of the existence of the bicyclic diketone shown in Scheme IV.

In 1956 Schlatter[10] described a process for synthesis of s-hydrindacenes through cyclialkylation of para-dialkyl substituted benzenoid molecules with a variety of compounds capable of forming carbonium ions in the presence of acid catalysts. Typical of this work is the cyclialkylation of p-diisopropylbenzene with isobutylene in the presence of hydrogen fluoride to yield 1,1,3,3,5,5,7,7-octamethyl-s-hydrindacene (2) as shown in Scheme V. The mechanism[10] is believed to

Scheme IV

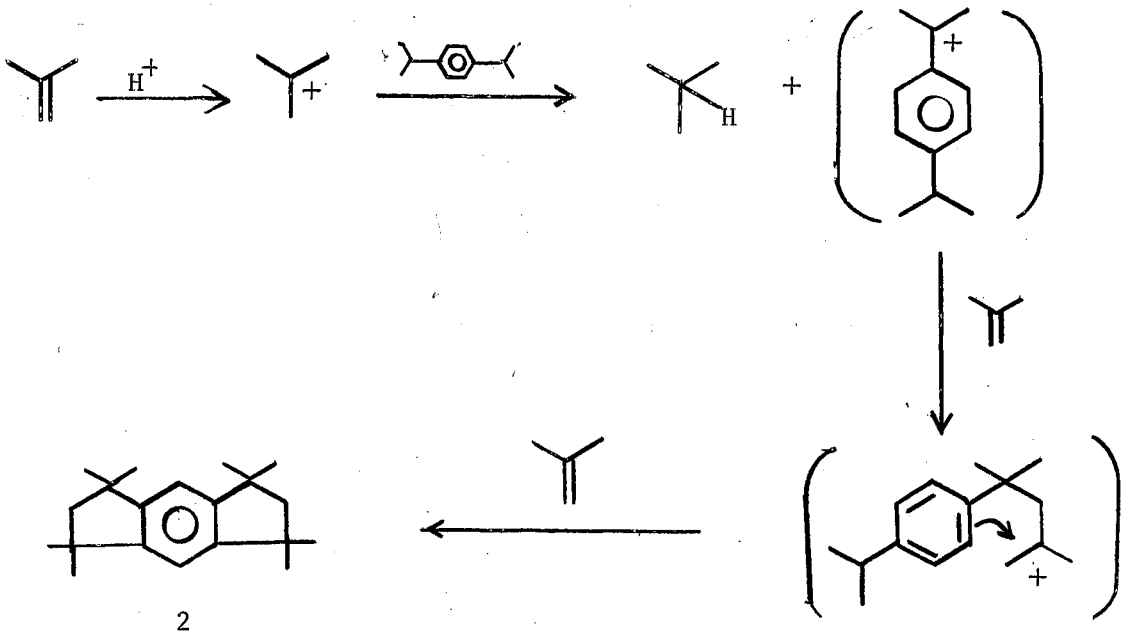


1

involve hydride abstraction by an isobutyl cation.

In 1958 Schmerling[11] described a one-step synthesis of 2 by a process involving a different mechanism and reactants. Essential to this kind of cyclialkylation is the presence of a conjugated diene in

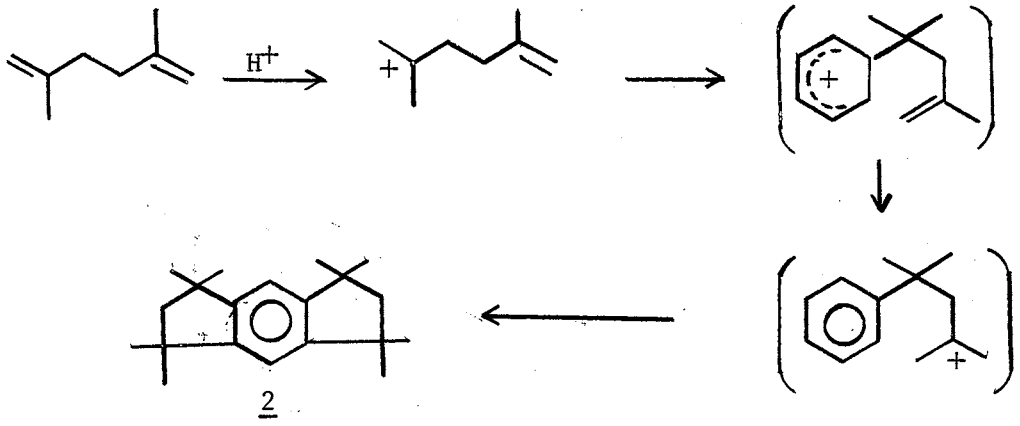
Scheme V



2

which at least one of the doubly bonded carbon atoms is tertiary. Two-stage cyclialkylation would produce the products reported by Schmerling as shown in Scheme VI. This patent[11] also reports that benzene and p-xylene were cyclialkylated with isoprene to give the corresponding hydrindacenes. These products will be described in greater detail in later chapters.

Scheme VI

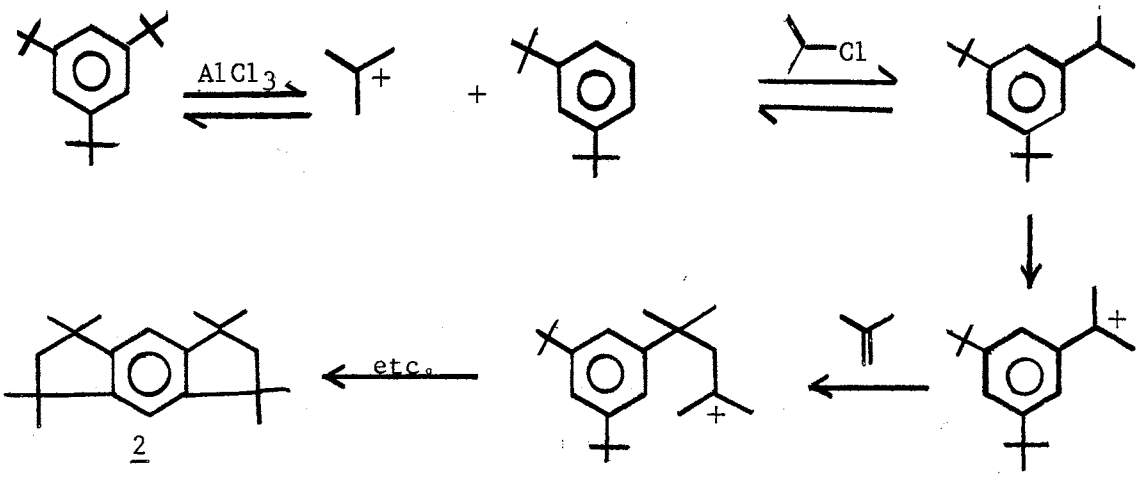


2

Synthesis of 2 was again reported in 1960 with the postulation of dealkylation and realkylation followed by hydride abstraction as the mechanism (Scheme VII) for cyclialkylation.[12] This reaction was extended by using 1,3,5-triisopropylbenzene and 2-methyl-2-butene in the synthesis of a decamethylhydrindacene shown in Scheme VIII.[12]

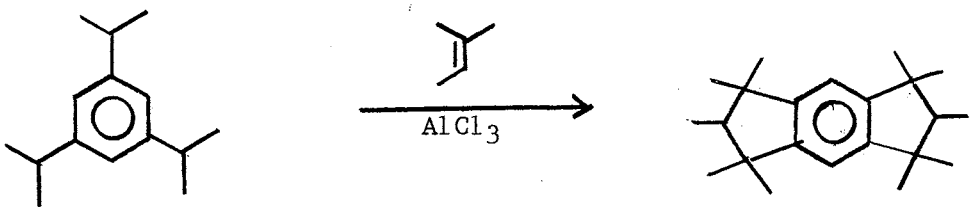
New importance for the synthesis of polyalkylhydrindacenes was provided in 1960 when Theimer and Blumenthal[13] disclosed that acetyl derivatives of benzene-derived hydrindacenes were commercially useful as musks. Their syntheses involved Grignard preparation of olefins which were cyclized to hydrindacenes. As an illustration,

Scheme VII



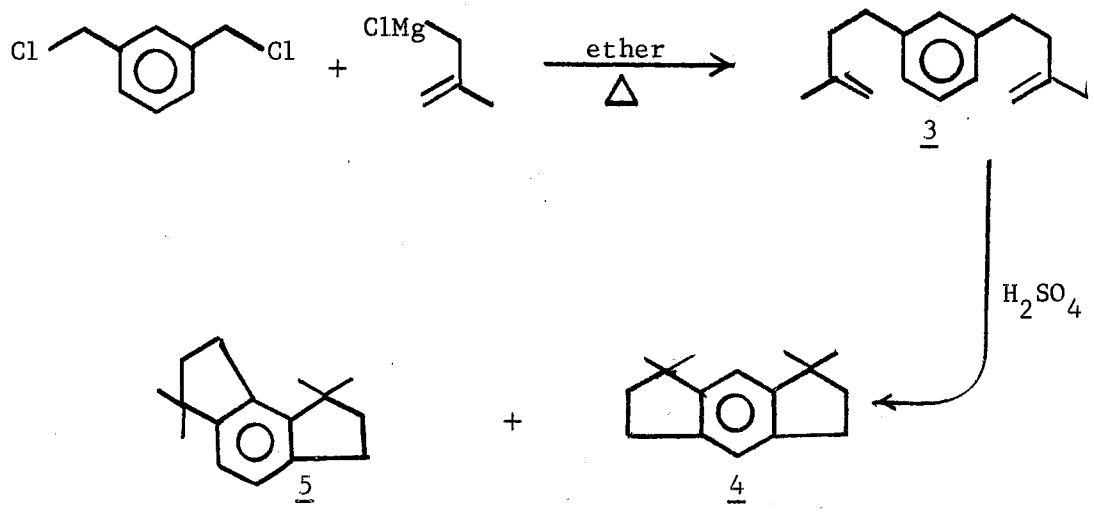
α,α-dichloro-m-xylene was treated with the Grignard reagent formed from methallyl chloride to produce the intermediate m-bis(3-methyl-3-butenyl)-benzene (3). This intermediate was cyclized (Scheme IX) to form a mixture of two isomers, 1,1,7,7-tetramethyl-s-hydrindacene (4) and 1,1,6,6-tetramethyl-as-hydrindacene (5).

Scheme VIII



Since the musk properties of an acetylated indan or hydrindacene are difficult to predict,[14,15,16] it has become of interest to the perfume industry to synthesize a broad variety of these compounds by patentable routes for use as acetylation intermediates. Nitration of

Scheme IX



indans has also produced useful musks and pre-emergence herbicides.[17,18] Consequently numerous patents covering indan and hydrindacene syntheses are held by perfume manufacturers.[3,13,15,17,19,20,21] Several comprehensive articles describing aromatic musk properties and structures have been published.[15,16,22] Some indans have pharmacological potential.[23] Indans and hydrindacenes are often mentioned in patents as high energy jet fuels but it is doubtful that this use will become economically feasible.

CHAPTER II

THE PRODUCTS

Earlier workers[4] concluded that the cyclialkylation of the xylenes with isoprene formed various indans and all the hexamethylhydrindacene isomers possible. It became of interest to identify and characterize the array of products resulting from the cyclialkylation of benzene with isoprene. Figure 1 is a gas-liquid chromatography (glc) chromatogram typical of mixtures from the use of 85-97% sulfuric acid catalyst.

Several factors have been observed to affect the yield and distribution of cyclialkylation reaction products obtained from isoprene. The concentration of sulfuric acid was found to have a marked effect.[4b] This was not surprising since it has long been known that sulfuric acid concentration is a prime factor in alkylation reactions involving olefins.[24,25] Cyclialkylation predominates at higher acid concentration (85-97%), whereas isoprene polymerization, ester formation,[26] and sulfonation[26] compete with cyclialkylation at intermediate acid strengths (50-80%). Cyclialkylation was not observed when the sulfuric acid strength was below 50%. When isoprene was exposed to 40-50% sulfuric acid, it was found that unsaturated and saturated cyclic ethers are the major products.[27,28] The optimum temperature for the cyclialkylation reaction depends upon the strength of acid used. Generally lower temperatures are essential when the concentration of the acid is

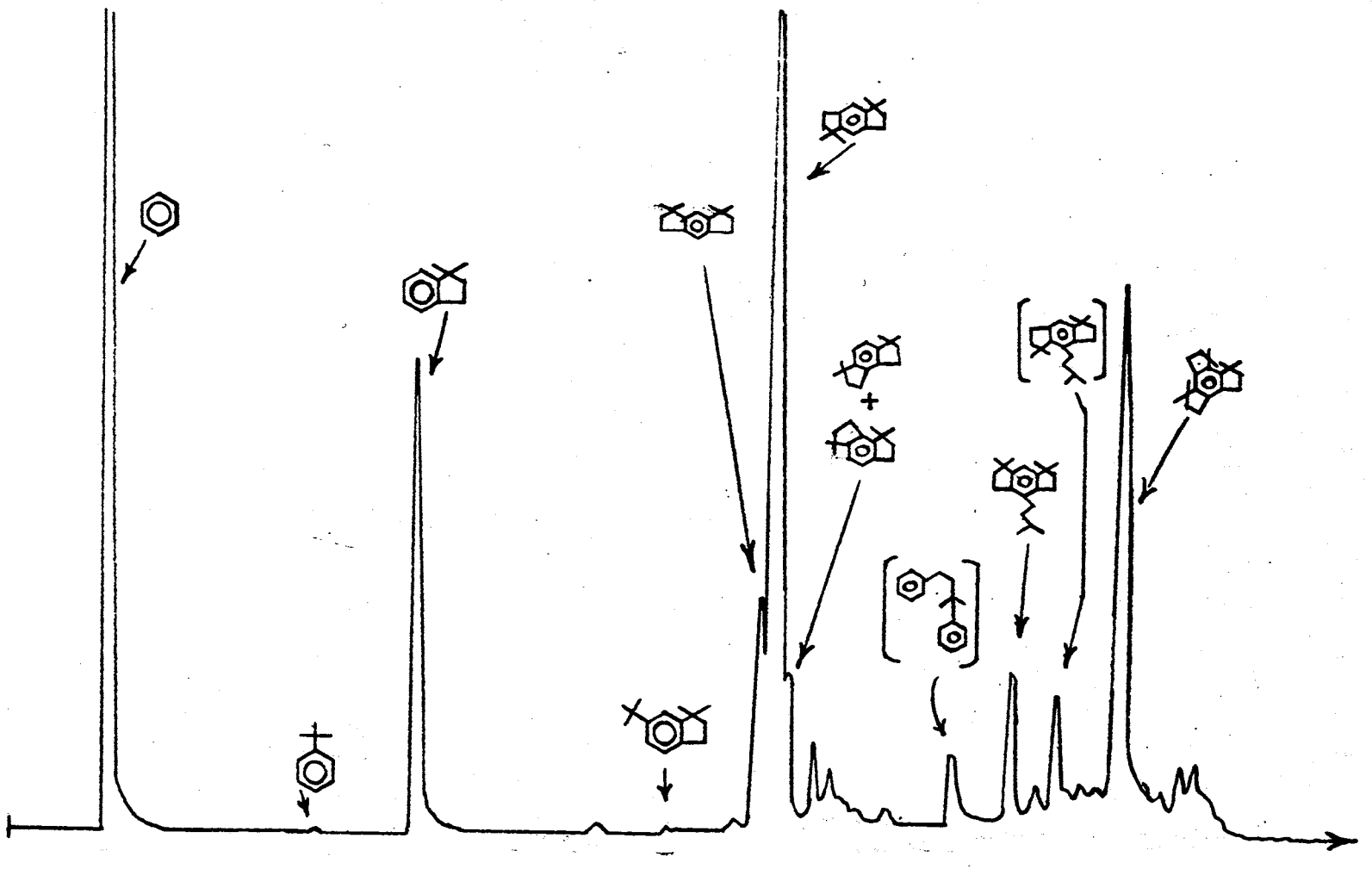


Figure 1. Gas Chromatogram of Benzene-Isoprene Cyclialkylation Reaction Products

increased.[4b] In the benzene-isoprene system it was convenient to use 97% sulfuric acid while maintaining the reaction temperature from 0-18° for best yields. Similar results with lower yields were obtained by using 85% sulfuric acid at 10-27°. Smaller-volume reaction mixtures (2 l.) in indented flasks with high speed stirring were found to give superior yields when compared to scaled-up runs (10 l.). This is a result of increased agitation, minimized local temperature rise, and shorter reaction time. Thus it was found that the yield of 1,1-dimethylindan (6) dropped from 3.5 to 2.3% when the reaction was conducted on a 10-l. scale compared to 2 l. Likewise the summed theoretical yields for all products changed from 24.1% to 17.8% owing to scale-up. Comparisons of glc data indicated that peak areas representing the hydrindacene fractions increased relative to those for other products when the volume of acid catalyst was decreased.

As previously reported,[11] cyclialkylation of benzene-isoprene mixtures gave reasonable amounts of 1,1,5,5-tetramethyl-s-hydrindacene (7) isolated by spontaneous crystallization. A low yield of 6 could also be obtained by distillation of the mixture under reduced pressure. The low ratio of indan to hydrindacene obtained from benzene and isoprene differed from that in other benzenoid cyclialkylation reactions, i.e. alkyl-substituted benzenes gave substantial amounts of indans.[4] This anomaly may be explained by comparing the reactivity of 6 to that of benzene. Since 6 is alkyl-substituted, it would be expected to react with the isoprenoid electrophile more readily than benzene. When 6 was treated with isoprene in the presence of sulfuric acid, a mixture of hydrindacenes resulted.[3] Figure 2 compares the glc analysis of the products of treating 6 with isoprene to that of the benzene-isoprene

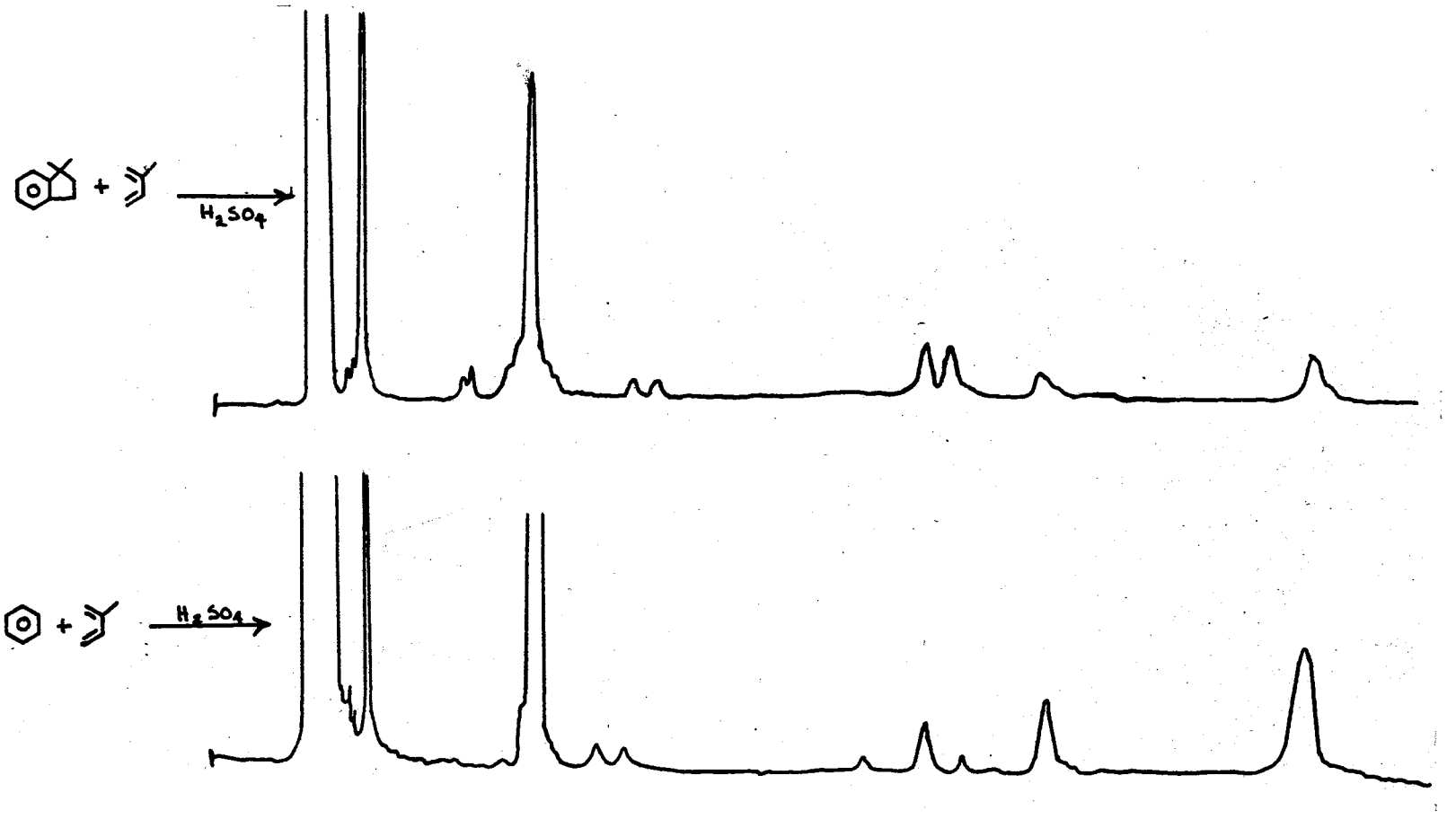
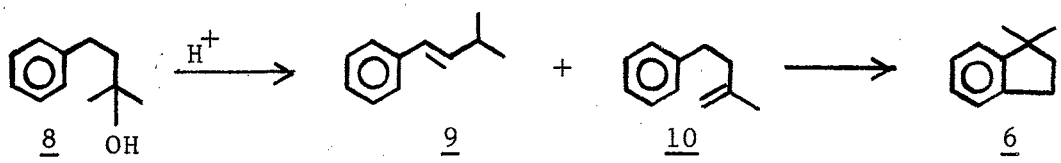


Figure 2. Treatment of 1,1-Dimethylindan (6) with Isoprene. Glc Comparison of the Results

cyclialkylation products. A large similarity is seen. Therefore it is logical to assume that 6 is a reactive intermediate in the formation of other cyclialkylation products. Being reactive, 5 does not accumulate and is consumed by further reaction. A low ratio of indan to hydrindacene product results.

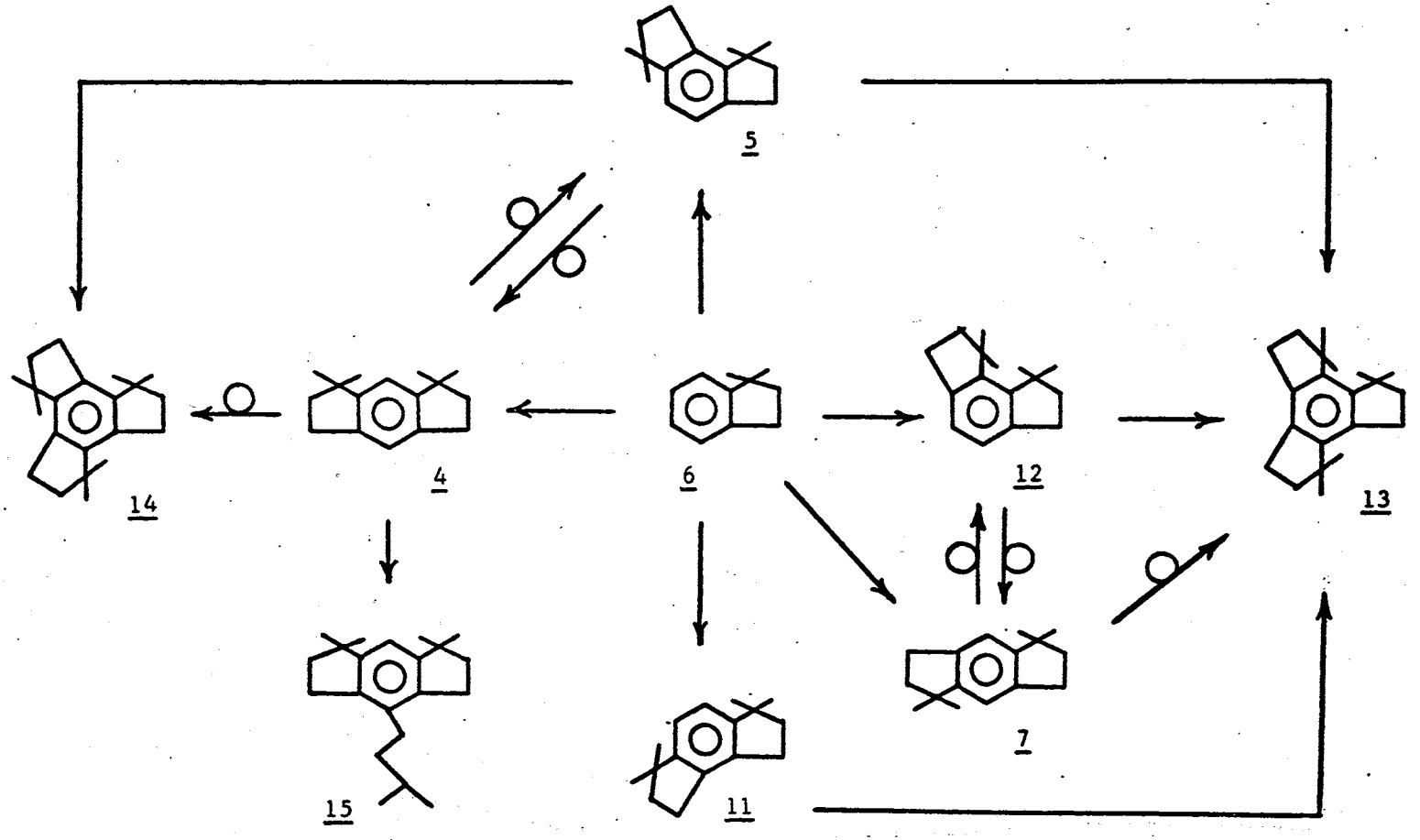
Large quantities of 6 were more conveniently obtained by treatment of 2-methyl-4-phenyl-1-butanol (8) with an acid catalyst to obtain a 4:1 mixture of 3-methyl-1-phenyl-1-butene (9) and 2-methyl-4-phenyl-1-butene (10).[29] Upon heating and lengthened contact with the catalyst these olefins cyclized to 6 as shown in Scheme X.

Scheme X



The question reamins whether other possible hydrindacene isomers of Scheme XI (3,3,6,6-tetramethyl-as-hydrindacene (11) and 1,1,8,8-tetramethyl-as-hydrindacene (12) are present in the reaction mixture. If not, do electronic or steric factors prevent their formation. The possible formation of 1,1,4,4,9,9-hexamethyltrindan (13), 1,1,4,4,7,7-hexamethyltrindan (14), and 4-isopentyl-1,1,7,7-tetramethyl-s-hydrindacene (15) was also of interest. Various glc substrates, e.g. Carbowax 20M, Bentone, Bentone/SE-52, UC W-98, SE-30, SE-31, SE-52, DC-55, and OV-101, in quarter-inch columns failed to separate the hydrindacene

Scheme XI



isomers. Satisfactory analytical separations were obtained using a DC-550 oil capillary glc column. Figure 3 depicts the chromatogram of the hydrindacene compounds detected in the crude benzene-isoprene cyclialkylation mixture. Four hydrindacenes were found. Calculations of peak areas using triangulation gave the ratios 3.0: 1.0: 1.7: 11.8 in order of elution of the compounds. These ratios correspond to percentages of 17.0: 5.7: 9.9: 67.4 respectively. Comparison of retention times to that of 7 and mixed injections showed that the final peak, comprising 67% of the hydrindacene fraction, represents 7.

By using preparative glc techniques, it was possible to isolate quantities of the compound that eluted first.[30] Upon standing, the collected fraction partially crystallized. Mass and nuclear magnetic resonance (nmr) spectra of this solid were consistent with the structure of 1,1,7,7-tetramethyl-s-hydrindacene (4). Isomer 4 was further purified to a material having the composition 98:2 (4:7) by preferential solubility in cold ether, in which 7 is less soluble.

Cyclization of m-bis(3-methyl-3-butenyl)benzene (3) prepared by the Grignard process of Theimer and Blumental[13] gave a 1:1 mixture of 4 and 5 as shown in Scheme IX. Separation of these two isomers was done by distilling them through a spinning band column under reduced pressure. Comparison of the nmr spectra of 4 obtained from cyclialkylation with that prepared from the Grignard process proved they had identical proton shifts. The mixture of 4 and 5 from the Grignard reaction and purified isomers were mixed with the crude cyclialkylation products and the mixture analyzed by glc. The results indicated that authentic 5 increased the area of the second peak eluted from the capillary glc column. It was therefore concluded that 5 was present

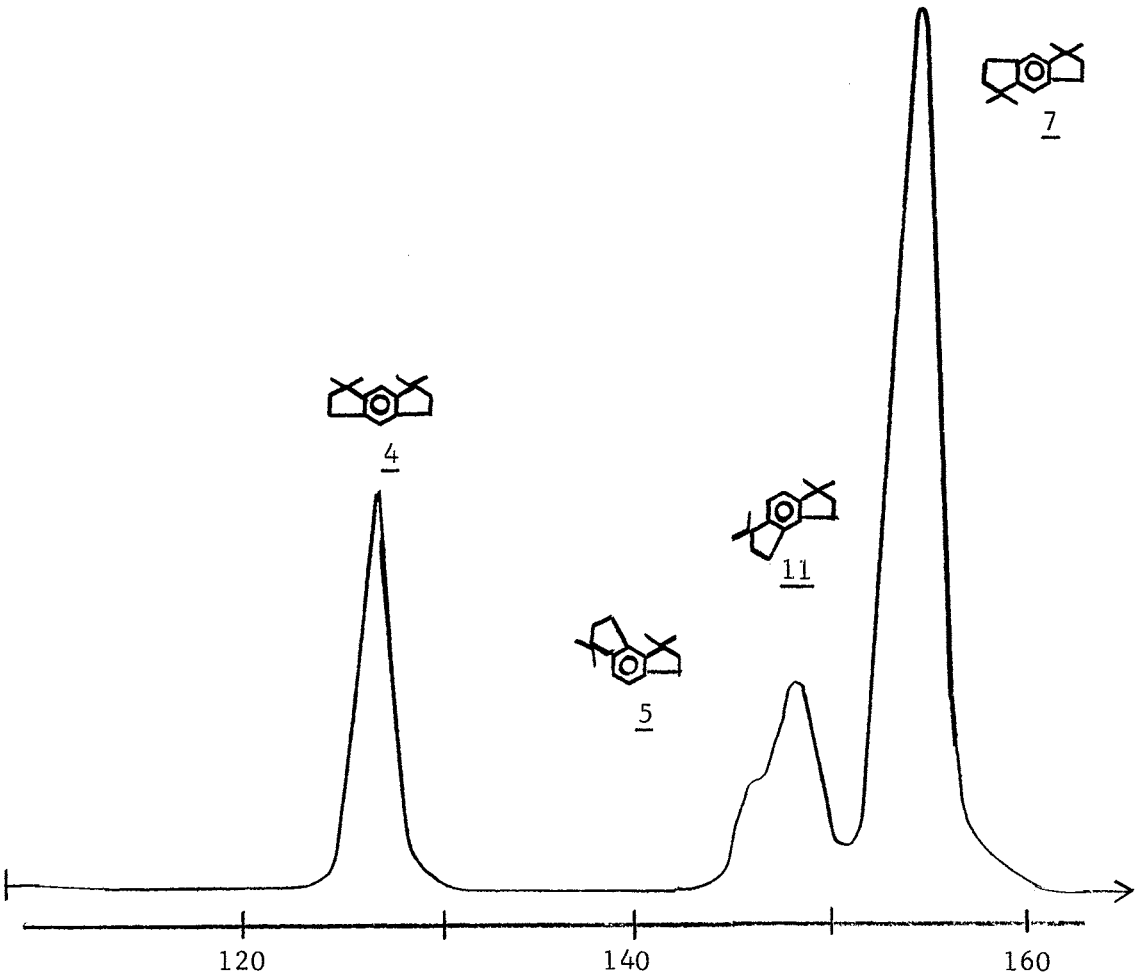
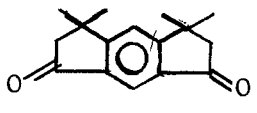


Figure 3. Gas Chromatogram of Benzene-Isoprene Hydrindacene Products

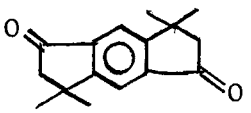
as the minor hydrindacene component (5.7%). Distillation, column chromatography, and preparative glc did not cause separation of 5 from the crude cyclialkylation mixture. Oxidation, using a selective chromic acid technique,[31] was performed on the hydrindacene fraction obtained from the distillation of crude cyclialkylation products. Mixed-injection glc comparisons of the monoketones from this treatment with those obtained by oxidation of a mixture of 4 and 5 obtained from the Grignard synthesis indicated that monoketones derived from 5 were

definitely present. Application of separative techniques failed to yield these ketones pure.

A dioxo derivative of 4, 3,3,5,5-tetramethyl-s-hydrindacen-1,7-dione (16) was isolated from the ketone mixtures by virtue of its insolubility in cold ether. The isomeric 3,3,7,7-tetramethyl-s-hydrindacen-1,5-dione (17) was obtained from ketone mixtures by preparative glc. The monooxo derivatives 3,3,7,7-tetramethyl-s-hydrindacen-1-one (18) and 3,3,5,5-tetramethyl-s-hydrindacen-1-one (19) were obtained by oxidation of the pure hydrindacenes, 7 and 4 respectively, followed by sublimation from the small amount of dioxo impurity.



16



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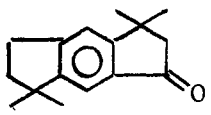

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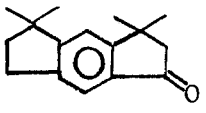
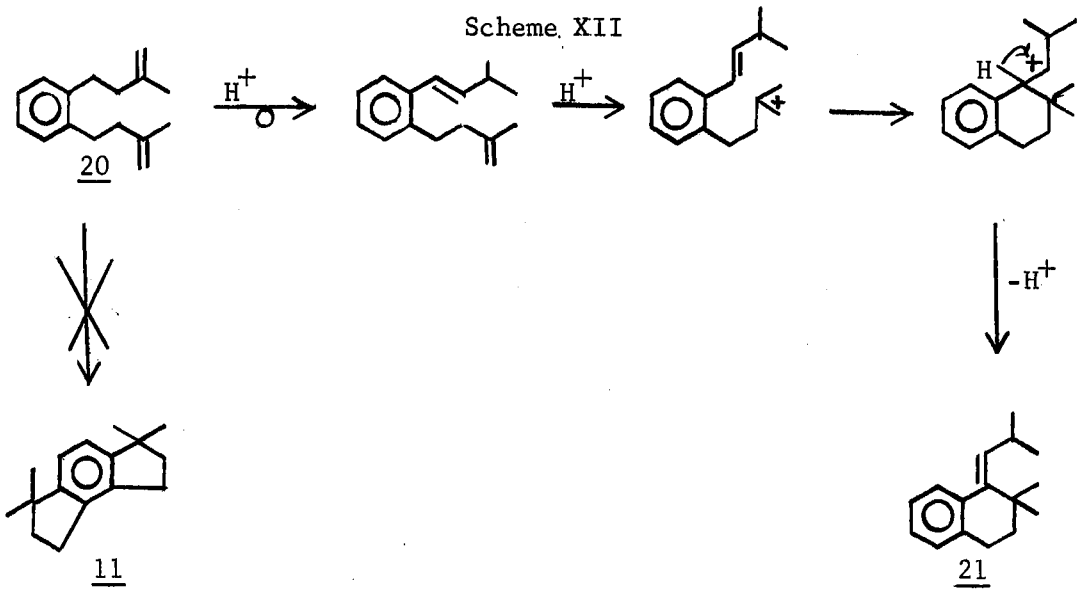


19

One glc peak in the hydrindacene fraction remained unassigned. It was therefore desirable to synthesize 3,3,6,6-tetramethyl-as-hydrindacene (11) by an independent route. The method of Theimer and Blumenthal[13] was used for preparation of o-bis(3-methyl-3-butenyl)-benzene (20). Acid-catalyzed reaction of this diene did not give the desired 11. Instead, a mixture containing 3,4-dihydro-2,2-dimethyl-1-isobutylidenenaphthalene (21) as the major product resulted. Compound 21 was isolated by preparative glc and tentatively identified through the use of infrared (ir), nmr, and mass spectroscopy. Scheme XII shows a possible route to formation of 21.

Scheme XII



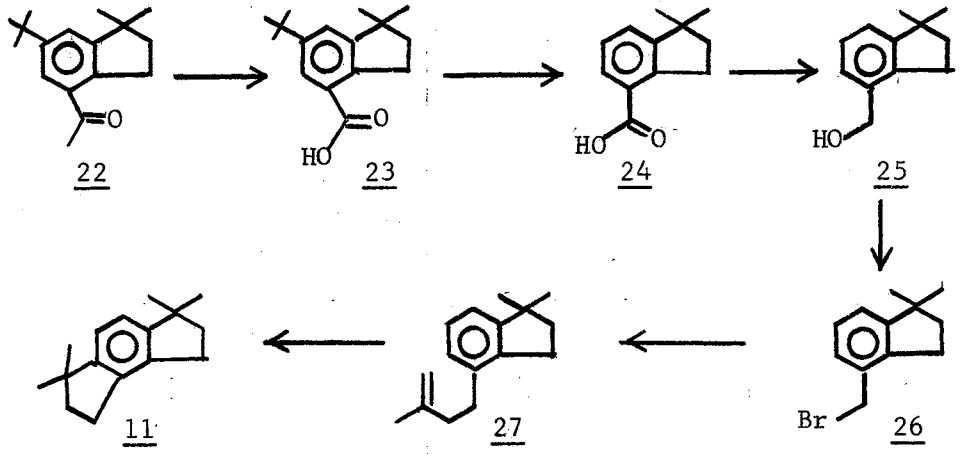
Shift of the terminal olefin bond, through a series of allylic migrations, into conjugation with the phenyl ring as shown is to be expected. This also occurred when 8 was dehydrated under conditions similar to those used for the reaction of 20. Alcohol 8 gave 80% of the conjugated olefin 9 under these conditions.[29]

The behavior of 3 and 20 in the presence of acid catalyst contrasted to the benzene-isoprene cyclialkylation reaction provided the following rationalizations. In the formation of hydrindacenes 4, 5, and 11 by cyclialkylation, apparently dienes play minor if not insignificant roles as intermediates. If dienes are intermediates it would appear that nearly equal quantities of 4 and 5 should be present in the cyclialkylation mixture. This was not found. Isomer 5 could preferentially react further leaving the observed excess of 4 (3:1, 4:5), but this seems unlikely from their behavior upon treatment with isoprene (see Fig. 4). Thus 4 and 5 probably did not arise from a diene intermediate. Also if dienes were major reaction intermediates, then 11

would be an insignificant product of the reaction and 21 should be observed. We have not found olefins as products from cyclialkylation.

The question of the presence of 11 as a reaction product remained unanswered. A second synthetic route shown in Scheme XIII was followed successfully. Treatment of 4-acetyl-1,1-dimethyl-6-tert-butylindan (22) with sodium hypobromite solution provided 1,1-dimethyl-6-tert-butylindan-4-carboxylic acid (23) which was treated with aluminum chloride in the presence of toluene to remove the t-butyl substituent and give 1,1-dimethylindan-4-carboxylic acid (24). The acid 24 was reduced with diisobutylaluminum hydride (DIBALH) to give 4-hydroxymethyl-1,1-dimethylindan (25) which was treated with anhydrous hydrogen bromide to provide 4-bromomethyl-1,1-dimethylindan (26). Grignard coupling of 26 with methallymagnesium chloride yielded 4-(3-methyl-3-butenyl)-1,1-dimethylindan (27) which was stirred with an acid catalyst to cyclize 27 to 11.

Scheme XIII

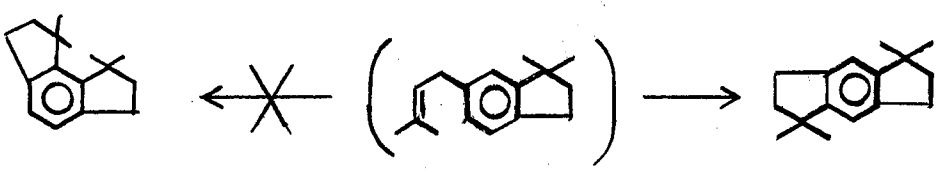


Once 11 became available, glc comparisons by mixed injections indicated that indeed the unidentified hydrindacene peak represented 11. By what route was 11 formed in the cyclialkylation reaction? Acid-catalyzed treatment of 20 showed it unlikely that 11 was formed from diolefin intermediates.

The above considerations led to the following hypothesis. Attack of an isoprenoid electrophile upon benzene results in formation of 6 by rapid cyclialkylation. Then and only then does another electrophile attack the remaining available positions on the aromatic ring of 6, with formation of hydrindacenes. Attack of hydrindacene aromatic positions would produce other, higher molecular weight compounds isolated from the reaction mixture.

Having accounted for all glc peaks in the hydrindacene range of retention times left one unobserved isomer to be considered. Examination of a molecular model of 1,1,8,8-tetramethyl-as-hydrindacene (12) shows considerable steric crowding of the gem-methyl groups. Consequently, formation and subsequent cyclization of the postulated intermediate 1,1-dimethyl-6-(3-methyl-2-butenyl)indan would give 7 rather than the sterically prohibited 12 as shown in Scheme XIV. These rationalizations exclude 12 as a benzene-isoprene cyclialkylation product.

Scheme XIV



12 7

Table I presents the nmr proton shifts found for the various hydrindacene isomers and derivatives.

The preceding theories require that the exposed aromatic positions of 6 are attacked during cyclialkylation. The observed ratios of hydrindacene isomers found in the reaction should parallel the availability of reaction sites. The products of Scheme XV show the site preference is C-6 > C-5 > C-4 > C-7 provided subsequent reactions do not preferentially deplete only certain specific tetramethylhydrindacenes from the reaction pool.

Scheme XV

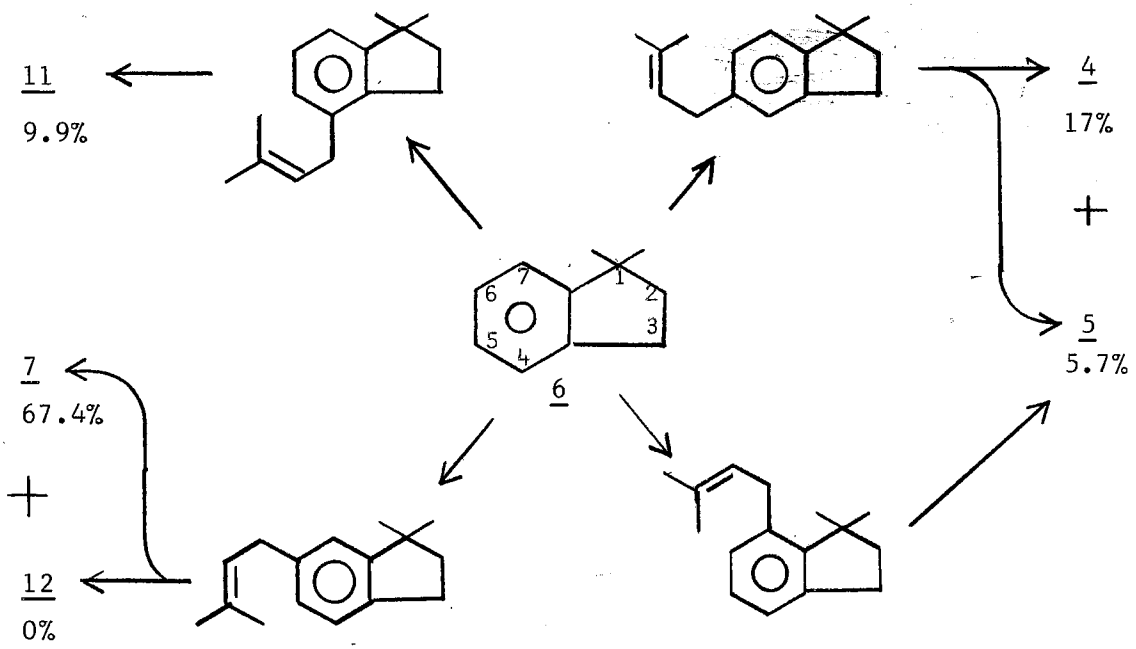
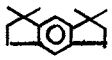
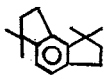
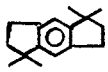
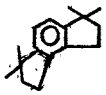
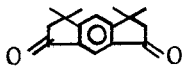
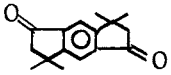
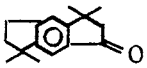
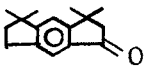
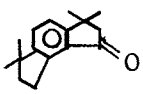


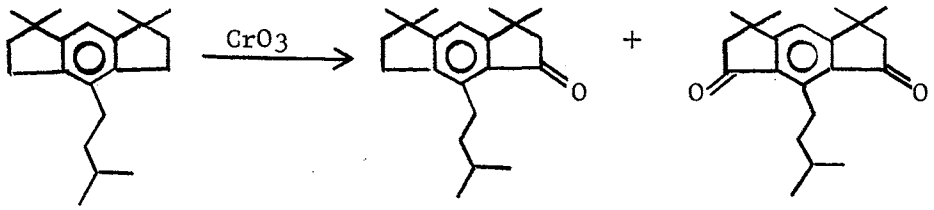
TABLE I

PROTON SHIFTS OF THE TETRAMETHYLHYDRINDACENES
AND SOME OXO DERIVATIVES

		Gem-Methyls			ArH	mp or bp
4		1.20	1.86	2.76	6.68 6.77	60-1°
5		1.20 1.27	1.84	2.75 2.87	6.74	66° (0.3 mm)
7		1.20	1.86	2.77	6.73	95-6°
11		1.20	1.87	2.69	6.73	35-6°
16		1.46	2.56	-	7.43 7.88	221-2°
17		1.46	2.56	-	7.63	203-4°
18		1.28 1.38	1.95 2.43	2.92	7.13 7.28	81°
19		1.30 1.42	1.97 2.47	2.93	7.09 7.39	98-9°
		1.24 1.38	1.96 2.41	3.12	7.13	57-9°

The hydrindacene 4 yields 1,1,7,7-tetramethyl-4-isopentyl-s-hydrindacene (15) as a major product of subsequent alkylation. The latter was isolated by preparative glc of the intermediate distillation fractions of the crude benzene-isoprene products. The ir, nmr, and mass spectra were consistent with this assignment. Oxidation of 15 gave 3,3,5,5-tetramethyl-8-isopentyl-s-hydrindacen-1-one (28) and 3,3,5,5-tetramethyl-8-isopentyl-s-hydrindacen-1,7-dione (29) shown in Scheme XVI. These were separated and purified by preparative glc. Dioxo derivative 29 was also easily isolated since it is insoluble in cold ether.

Scheme XVI



15 28 29

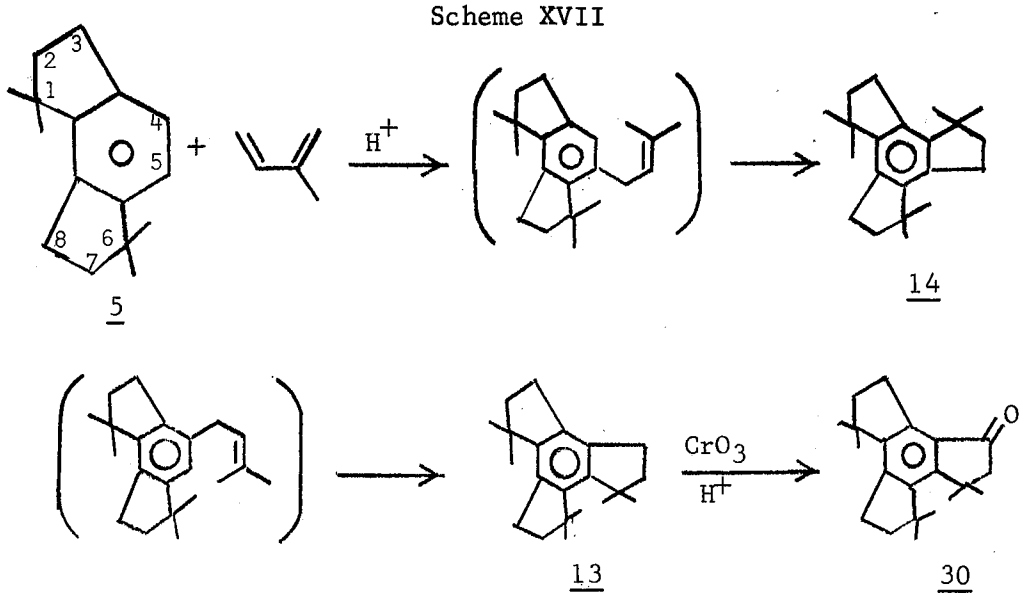
Another product obtainable from hydrindacene precursors is the novel hexamethyltrindan 13 (Scheme XI). It was isolated as a crystalline product from the late distillation cuts of the crude reaction mixture. The ir, nmr, and mass spectra were consistent with the assigned structure. Glc studies of the products of oxidation of 13 showed seven peaks, consistent with the predicted formation of three mono-, three di-, and one trioxo derivatives. One of the monooxo products,

3,3,4,4,9,9-hexamethyltrindan-1-one (30), was isolated by preparative glc.

It would be expected that if 1,1,4,4,7,7-hexamethyltrindan (14) formed in significant quantity it would precipitate as a solid. No evidence for the presence of 14 was found. The following tests were used to learn whether it was present. The distillation fraction, mainly 13, was oxidized and the products derivatized with Girard T reagent. Hydrolysis of this derivative yielded a mixture with glc peaks having identical retention times to the ketones prepared from pure 13. Mixed injections showed no differentiation by glc. To test further for the formation of 14, a 1:1 mixture of 4 and 5, the only direct precursors of 14 as shown in Scheme XI, was treated with isoprene. Glc analysis failed to show formation of a trindan product as seen in Figure 4. Hydrindacene 5 would be the expected intermediate in formation of 14 since it need not rearrange as hydrindacene 4 must. But it may be reasoned that if 5 was a precursor to any trindan, then attack of the isoprenoid allyl cation (see Chapter III) upon 5 would be greatly favored at the less crowded 4-position to give 13 rather than the more hindered 5-position to give 14 (see Scheme XVII). Instead it was concluded after treatment of 4 and 5 with isoprene (Fig. 4) that 5 does not give 13 or 14. Thus 5 is not an intermediate to the formation of trindans. It should be noted that the latter study was carried out with added trifluoroacetic acid (TFA).

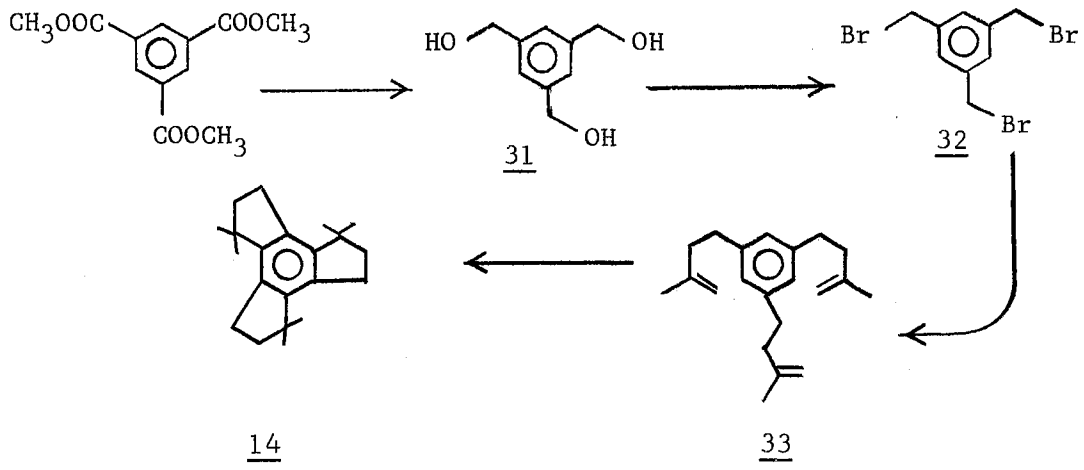
The question of formation of 14 by cyclialkylation was further investigated after it was synthesized by the route shown in Scheme XVIII. Reduction of trimethyl-1,3,5-benzenetricarboxylate with DIBALH gave 1,3,5-tris(hydroxymethyl)-benzene (31) which was converted to

Scheme XVII



1,3,5-tris(bromomethyl)benzene (32) by treatment of 31 with anhydrous hydrogen bromide. The tribromo-compound was coupled with methallylmagnesium chloride to give 1,3,5-tris(3-methyl-3-butenyl)benzene (33). Acid-catalyzed cyclization of 33 yielded 14.

Scheme XVIII



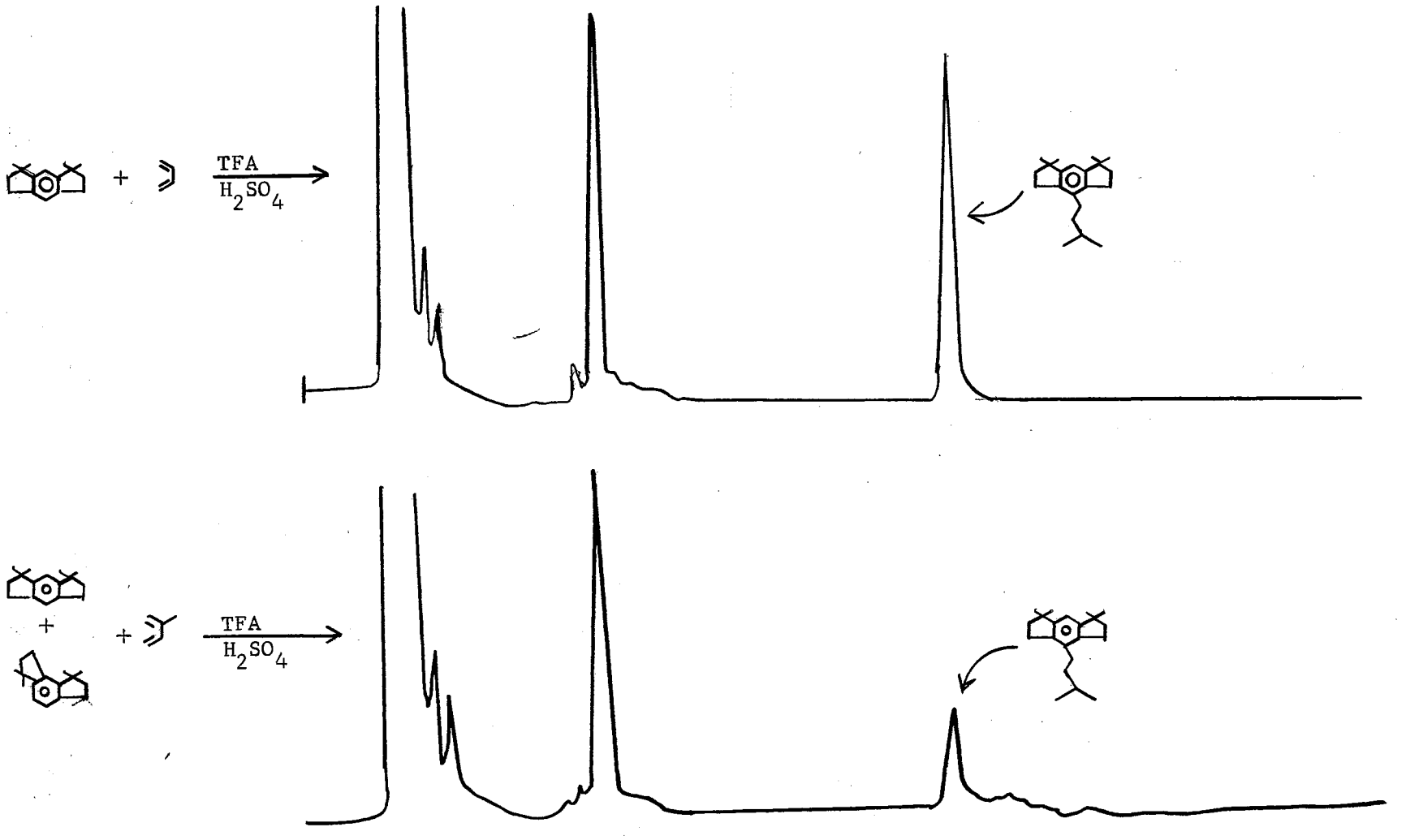


Figure 4. Isoprene Treatment of Hydrindacene Isomers. Glc Comparisons

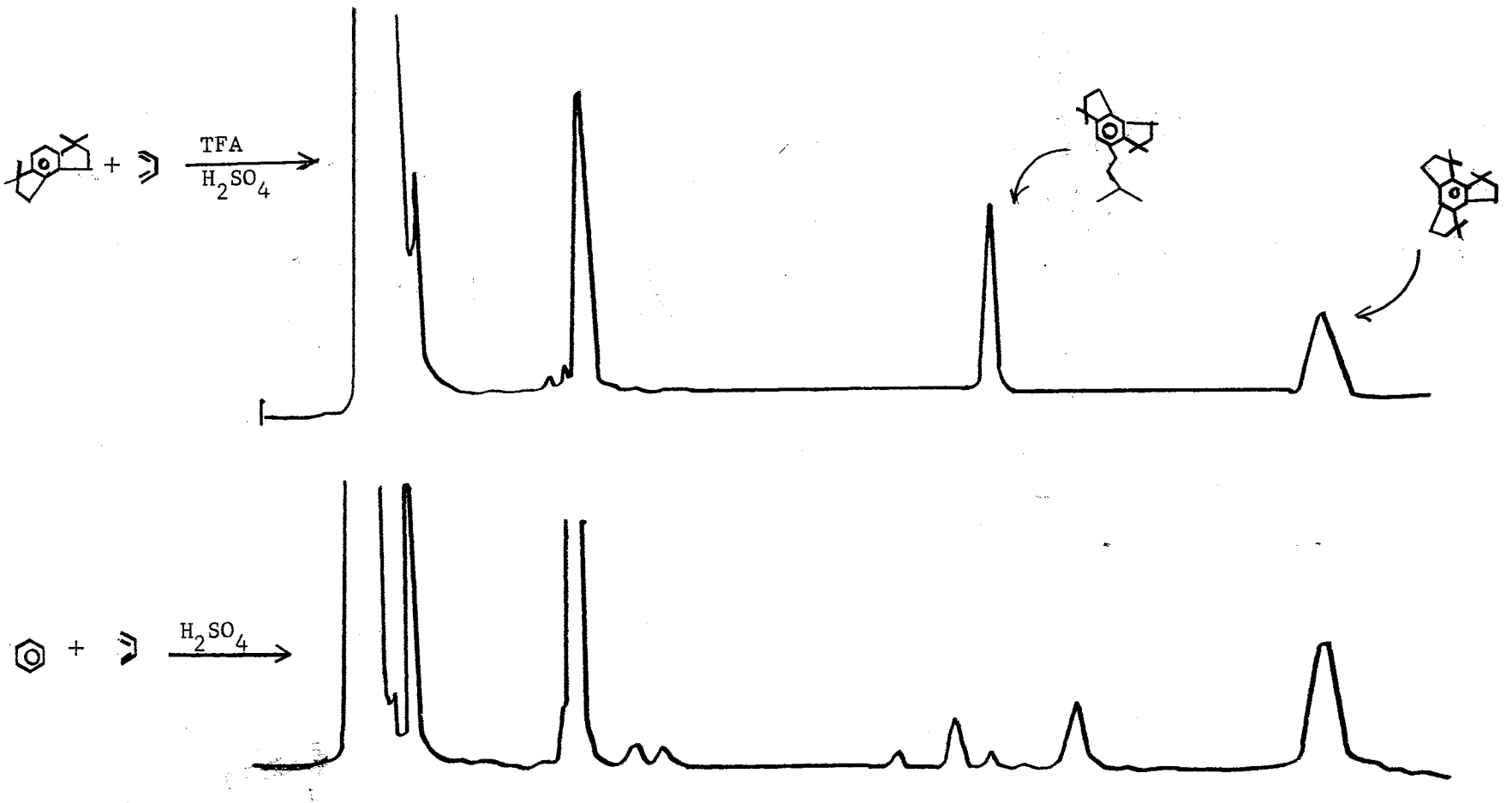


Figure 4 (continued)

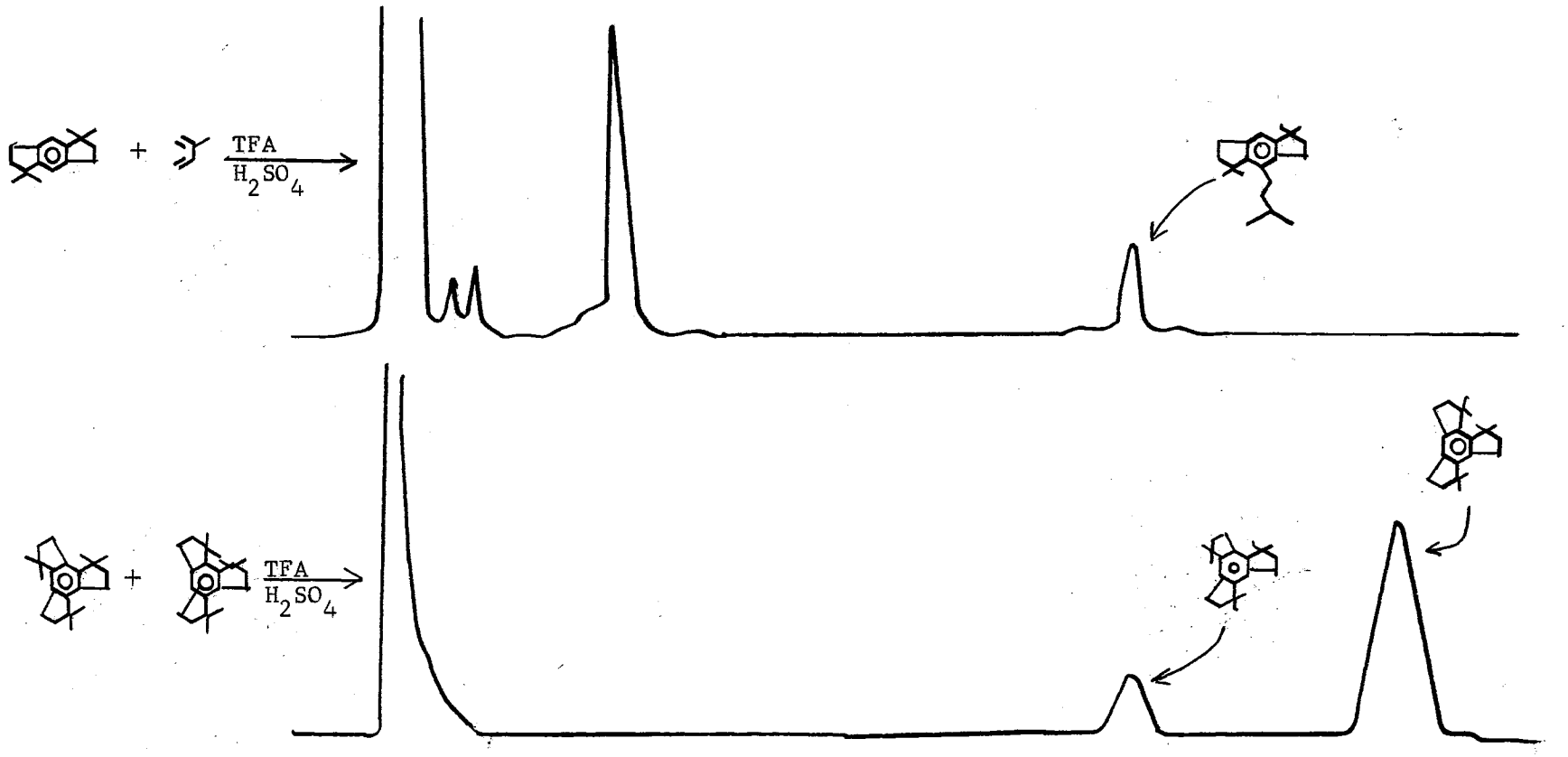


Figure 4 (continued)

Chromic acid oxidation of 14 gave three major products as detected by glc analysis. This is consistent with the formation of one mono-, one di-, and one trioxo derivative.

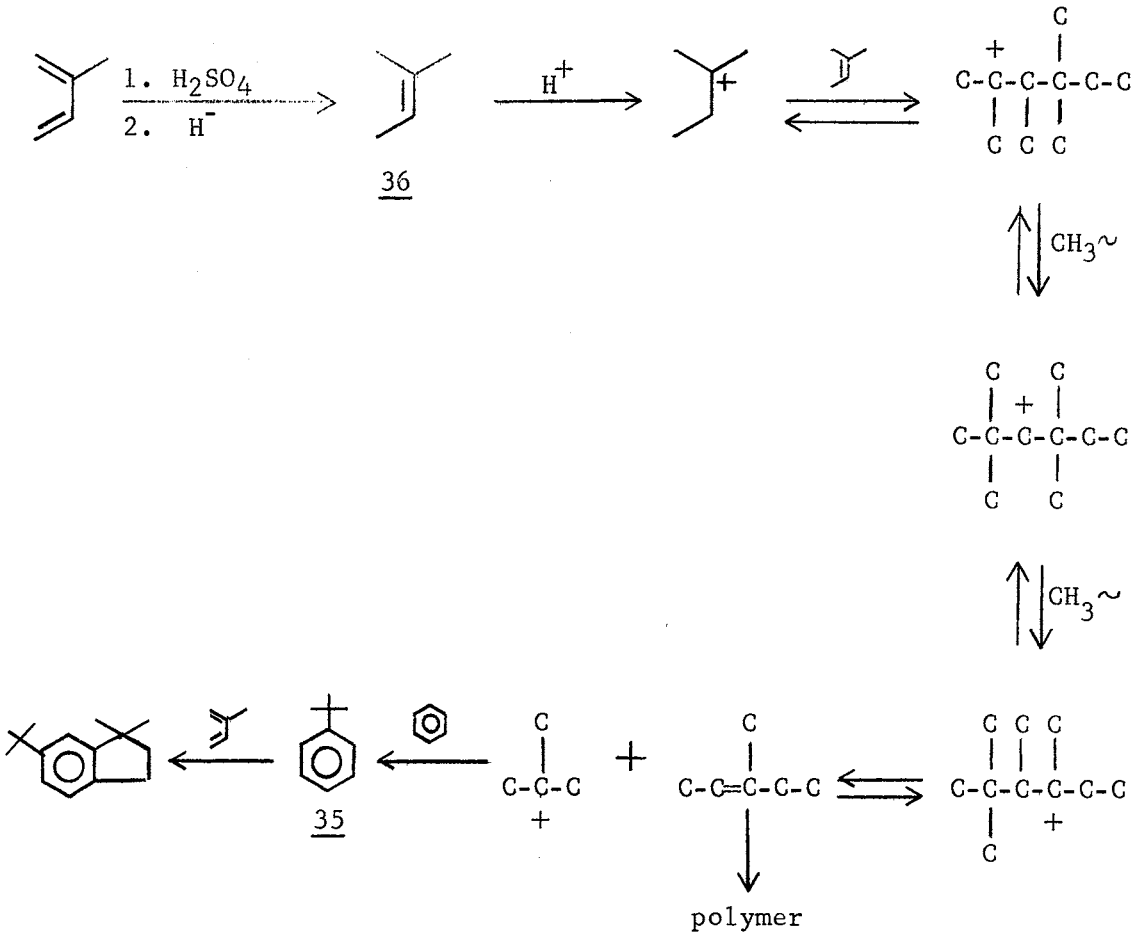
Mixed injections of 14 with the cyclialkylation reaction mixture showed that some product of the crude cyclialkylation mixture had a retention time indistinguishable from that of 14. Still it was difficult to accept that 14 was present in the amounts indicated by this comparison. Except for 5 there is no direct precursor to the formation of 14. Results reported above indicated that 5 was a questionable precursor. Also the authentic compound was poorly soluble in most organic solvents and possessed a high melting point. With these properties it would likely crystallize spontaneously from the crude reaction mixture. But only two compounds of the cyclialkylation mixture, 7 and 13 were found to exhibit this behavior.

Therefore it became necessary to establish the response of all available hydrindacene isomers when treated with isoprene. It was essential to create conditions suitable to attain formation and attack of the isoprenoid electrophiles in the absence of benzene as a solvent. The following solvents were tried but gave no success; petroleum ether[32] cyclohexane, and methanesulfonic acid. Using sulfuric acid as the catalyst with these solvents gave no glc-detectable formation of anything but isoprene polymers. The starting hydrocarbon was largely unconsumed. Chlorobenzene-sulfuric acid mixtures gave some indication that the desired reactions were occurring. Far superior results were achieved by using trifluoroacetic acid-sulfuric acid, with petroleum ether[32] as a co-solvent. The starting hydrocarbon was nearly consumed in this reactive system.

Using these conditions the acid-catalyzed behavior of the hydrindacenes in the presence of isoprene was determined. Figure 4 shows glc chromatograms of the products resulting from these treatments. From these chromatograms it was evident that only 4, 7, and 11 were precursors to products detected in the benzene-isoprene cyclialkylation reaction. As stated earlier, hydrindacene 5 apparently is not a precursor to trindans. Instead 11 is the presumed intermediate to 13. The reaction of 7 gave a product which probably was 1,1,5,5-tetramethyl-4-isopentyl-s-hydrindacene (34). This product and 14 show indistinguishable glc retention times on mixed injection. Barring the unlikely formation of 14 from 7, it was concluded that the glc peak of the crude cyclialkylation reaction showing identical retention time to 14 actually represents 34. Thus 14 is at most an insignificant product of cyclialkylation reactions.

Tert-butylbenzene (35) was identified as a minor product from the benzene-isoprene cyclialkylation reaction. The formation of 35 can be rationalized from the findings of Friedman and Morritz,[33] who showed that 2-methyl-2-butene (36) dimerizes and then fragments to give tert-butyl cation. This cation subsequently reacts with benzene. Scheme XIX presents a possible path for the formation of 36, which would then react as stated to yield 35. A small glc peak of identical retention time to that of 1,1-dimethyl-6-tert-butylindan was observed in oversize glc injections. Formation of this indan would be expected under cyclialkylation conditions.

Scheme XIX



CHAPTER III

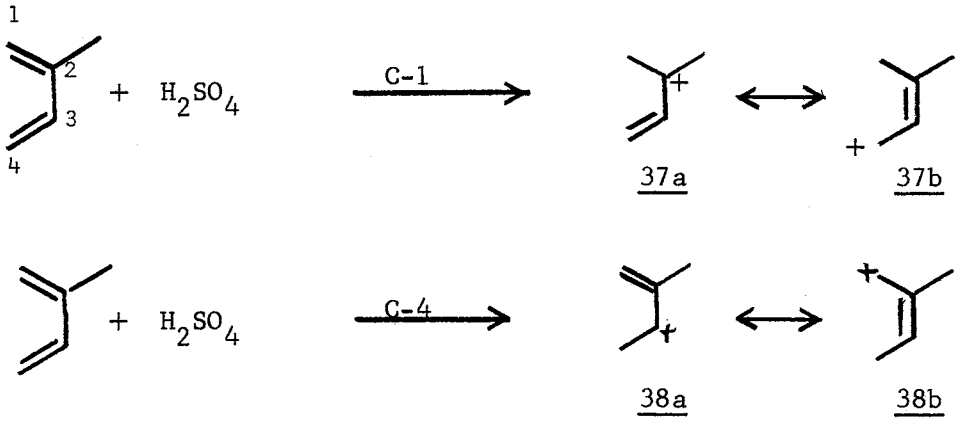
THE MECHANISM

The properties and distribution of products formed from cyclialkylation of isoprene and arenes have largely been previously described.[4] As stated, the cyclialkylation reaction predominantly yields indan and hydrindacene products. Several mechanisms are possible to achieve this formation.

To clarify the mechanism of cyclialkylation involving isoprene the likely behavior of this diene in the presence of the strong protonic acid, sulfuric acid, should be considered. The expected hybrid species are shown in Scheme XX.

Protonation at C-1 of isoprene would be predicted from electron density values calculated from simple LCAO theory[34] to create 37a, a tertiary allylic cation having a canonical form[35] 37b that represents

Scheme XX

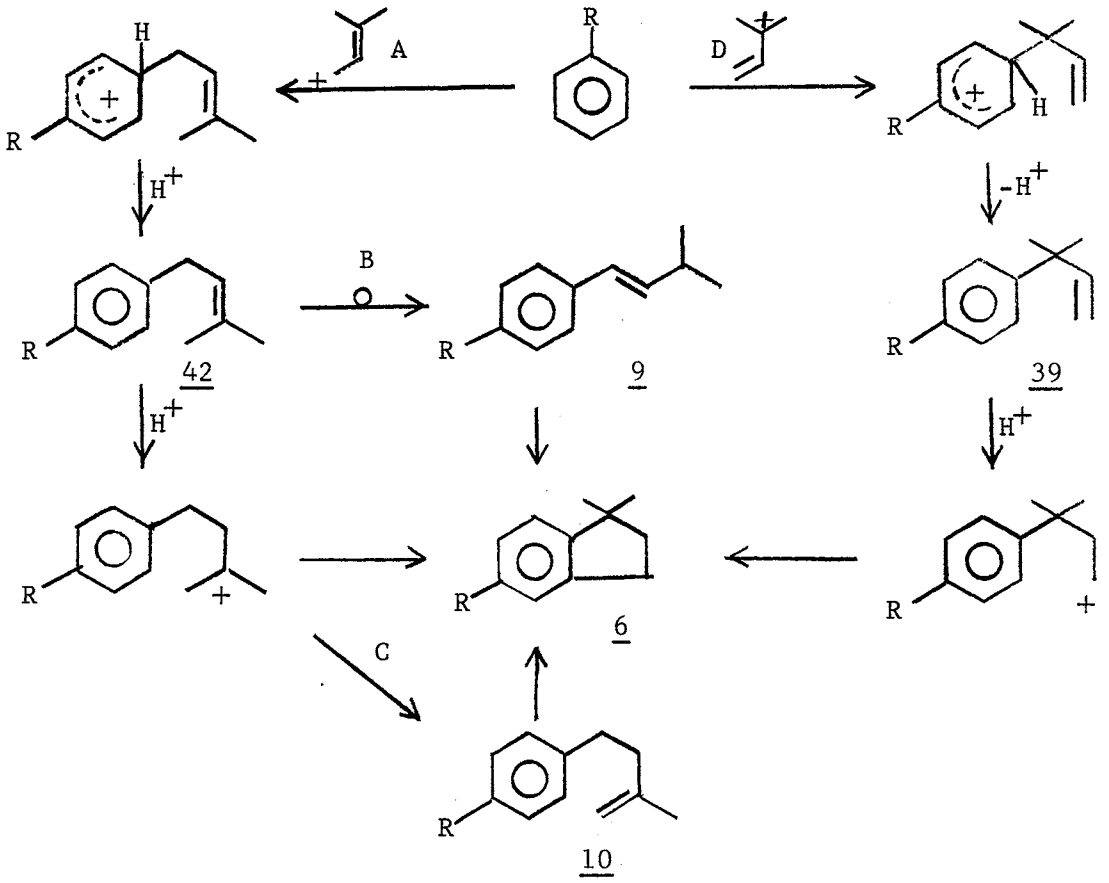


a primary allylic cation. Protonation at C-4 yields the resonance hybrid with canonical forms 38a, a secondary allylic ion, and 38b, a substituted primary allylic cation. Cyclialkylation products of isoprene and arenes that would arise from attack of the resonance hybrid 38a-38b have not been reported. Thus it may be concluded that these resonance forms play an insignificant role in isoprene-arene cyclialkylation with sulfuric acid catalyst.

Participation of structures 37a and 37b is less clear. Indan formation by cyclialkylation of isoprene and arenes can be rationalized using routes A, B, C, D or combinations of these as depicted in Scheme XXI.

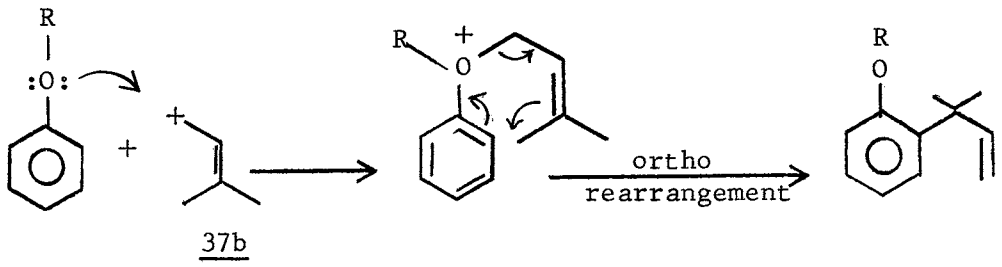
Is formation and subsequent cyclization of 3-methyl-3-phenyl-1-butene (39) (R = H) and derivatives as shown in route D (Scheme XXI) possible? Formation of derivatives of 39 (R = CH_3O-, C_2H_5O-) in a cyclialkylation reaction with isoprene has been reported.[36,37] In these reports it is claimed that ortho alkoxy derivatives of 39 form in significant quantity, dependent upon conditions of the reaction. Ortho-phosphoric acid was used as the catalyst. The presence of high ratios of ortho- to para-substituted products, which contradict predictions based upon steric factors, suggests that an unusual mechanism may be involved. The Claisen rearrangement of allylic ethers is believed to proceed via a cyclic transition state to give a predominately ortho-substituted product. This rearrangement is accompanied by an allylic shift.[38] Attack of electrophile 37b upon the ether oxygen atom to form a complex transition species, followed by a Claisen-type rearrangement as set forth in Scheme XXII, explains the reported results.[36,37]

Scheme XXI



A product resembling 39 was isolated from the products of cyclialkylation of tert-butylbenzene with isoprene. In addition to indan

Scheme XXII



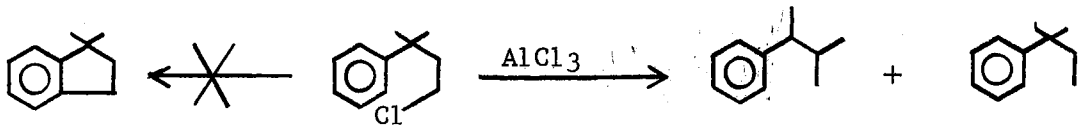
products a slight amount of p-tert-butyl-tert-pentylbenzene (40) was found to be present. This compound could be isolated after chromic acid oxidation of the indans that were present (the indans are described in greater detail in Chapter IV). Oxidation did not affect 40 and left it to be easily removed from the resultant indanones by preparative glc. Presumably 40 resulted from formation of a derivative of 39 (R = $(CH_3)_3C$-). Protonation of this derivative followed by hydride abstraction could form 40. Hydrocarbon 40 is the only product identified so far from cyclialkylation with sulfuric acid catalyst that could result from attack of a tertiary carbon cation. It is significant that the yield of 40 was less than 1%. This suggests that tertiary allylic cations play minor roles as electrophiles in cyclialkylation reactions.

Several other explanations which account for the minute amount of 40 found cannot be neglected. The isoprene used in the cyclialkylation reactions was of 99 mol % purity. If 2-methyl-2-butene (36) was an impurity, it would readily form a tertiary alkyl cation which would directly alkylate the arene. Likewise, as discussed earlier, the isoprenoid electrophile could form 36 by hydride abstraction.

Treatment of 1-chloro-3-methyl-3-phenylbutane with aluminum chloride did not give cyclized products.[39] Instead methyl migration took place. Thus cyclization of derivatives of 39 seems unlikely (Scheme XXIII).

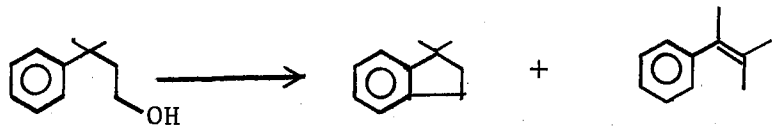
But when 3-methyl-3-phenyl-1-butanol (41) was heated in acid, a significant quantity of cyclized product was found as shown in Scheme XXIV.[40] Orthophosphoric acid was used as the catalyst at 230°. Under similar conditions the para-methyl derivative of 41 gave an increased

Scheme XXIII



yield of indan products.[41] Anchimeric assistance was suggested to account for the products shown in Scheme XXV. It was recognized[41] that the postulated mechanism of Ar_1-4 anchimeric assistance does not adequately account for the major cyclized product, 1,1,4-trimethylindan.

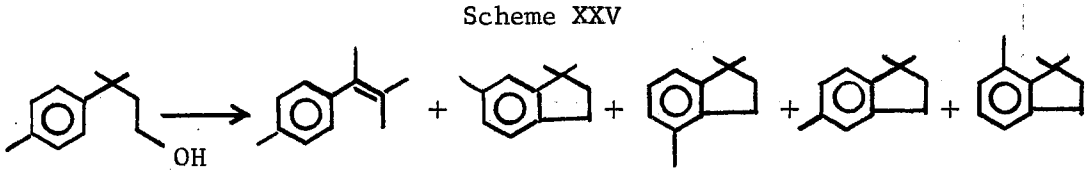
Scheme XXIV



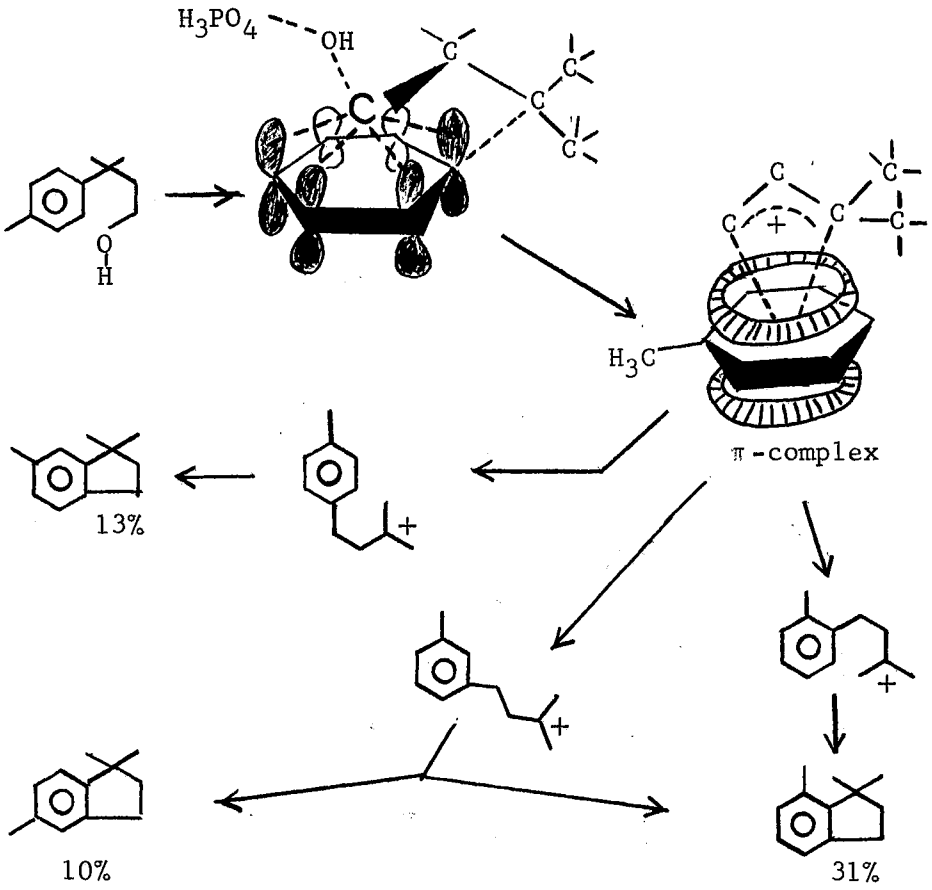
41 6

One could invoke uncommon Ar_3-6 participation to rationalize the results but a more attractive route reasonably compatible with our findings is presented in Scheme XXVI. In this mechanism, suggested by Dewar's comments,[42] participation of the aromatic pi-electrons results in formation of a pi complex. The pi complex would collapse to sigma

Scheme XXV



Scheme XXVI



bonded tertiary carbonium ions capable of cyclizing to the reported indans. Electron density around the arene system and probability of attack at different possible attachment sites would govern distribution of the cyclized products. In a recent paper Olah describes his conclusions about electrophilic aromatic substitutions.[43] Olah writes,

> "In exothermic reactions of low substrate selectivity the transition state of highest energy is of a pi complex nature. In this case a highly reactive electrophile interacts with the aromatic substrate (like toluene) with relatively little deformation of the latter in the transition state. The generally very fast reactions take place with little substrate discrimination (as pi bases) and can be considered as, or close to, encounter controlled. Subsequent σ-complex formation leads to positional selectivity. In

> these reactions, the complexes themselves also lie relatively early on the reaction path, and therefore ortho substitution is favored over para and, of course, meta."

Although anchimeric assistance cannot be ruled out with complete certainty, it does not adequately explain the products and distribution of the reaction. This type of assistance would be even less likely in cyclialkylation reactions.

To answer questions about the possible olefin intermediates depicted in Scheme XXI, each was synthesized and subjected to cyclialkylation conditions. These olefins were obtained; 39 (R = H), 3-methyl-1-phenyl-1-butene (9), 2-methyl-3-phenyl-1-butene (10), and 2-methyl-4-phenyl-2-butene (42). After each olefin was subjected to identical cyclialkylation conditions the reaction mixture was analysed by glc. Chromatograms of the products of each reaction mixture were compared to a chromatogram of authentic benzene-isoprene cyclialkylation products obtained under identical conditions. The results are shown in Figure 5.

Subjected to cyclialkylation conditions, olefin 9 formed only a small amount of cyclized 5. Glc analysis revealed a complex mixture of saturated dimers having molecular weights of 292. An isolable (by preparative glc) amount of 3-methyl-1,1-diphenylbutane (43) was also found to be present. Mixed injections and comparisons of glc retention times indicated that substances corresponding to 43 and three of the dimers were not appreciably present in the actual cyclialkylation mixture. This suggests that 9 is probably not a significant intermediate in the cyclialkylation reaction. Therefore route B (Scheme XXI) is of doubtful importance.

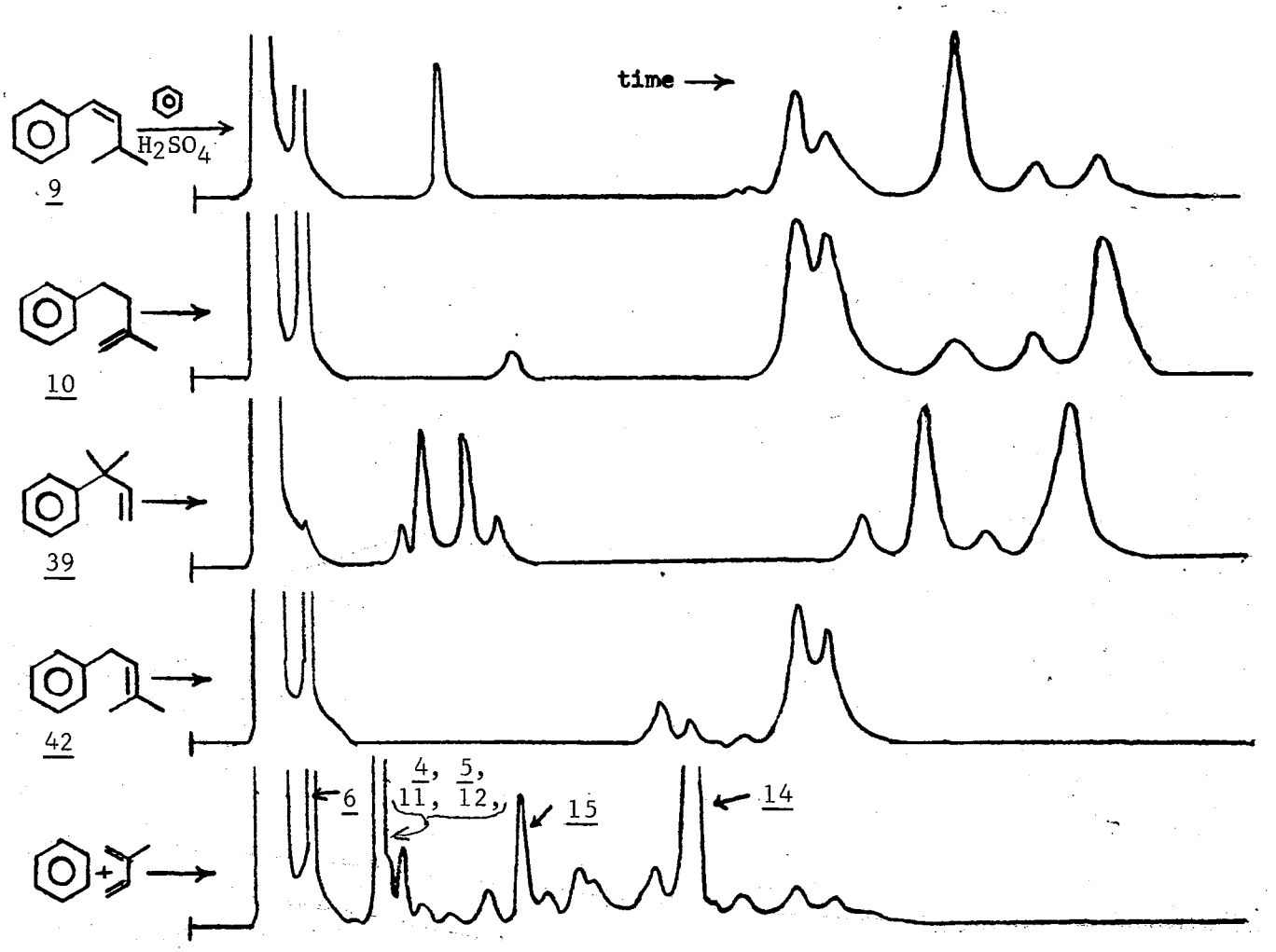


Figure 5. Comparison of the Gas Chromatograms of Selected Olefins After Reaction with Sulfuric Acid

As would be expected, olefin 10 readily produced 6 when subjected to cyclialkylation conditions. In addition to 6, glc analysis indicated formation of five dimers and a slight amount of product suspected of being 3-methyl-1,3-diphenylbutane (44). Although this product could not be isolated it exhibited a glc retention time similar to that of 43. The formation of 44 could be expected assuming that a tertiary carbonium ion would result from protonation of 10. Attack of such a cation upon benzene would produce 44. The retention times of mixtures indicated that three of the dimers formed from 10 could not be present in significant amounts in the actual cyclialkylation products. Thus it is likely that formation of 10 and subsequently path C (Scheme XXI) are of minor importance in cyclialkylation reactions.

When olefin 39 was subjected to cyclialkylation conditions, the predominant products detected by glc analysis resulted from alkylation of benzene and dimerization of 39. Glc analysis clearly showed that 6 was absent. Instead periodic sampling and glc analysis showed that 39 survived cyclialkylation conditions longer than all the other olefins. This study also showed the presence of a slight amount of reactive intermediate product as evidenced by a glc peak which appeared but later decreased in size. Mixed glc injections with authentic samples of 2-methyl-3-phenylbutane and 2-phenylpentane eliminated these possibilities. Also the glc peak disappeared from chromatograms of reaction samples that were treated with bromine. The disappearance of the glc peak suggests that it represents an olefin species. From Roberts' work[40] it is likely that the intermediate is 1-methyl-2-phenyl-2-butene. This styrene derivative would be expected

to undergo further alkylation and dimerization when protonated in the presence of benzene. Additionally 39 did give four alkylation products from attack of benzene, having molecular weight of 224 and four dimeric products. Comparing these results to those of cyclialkylation showed lack of correlation of any retention times. Table II represents a summary of the results obtained after subjecting the described olefins to cyclialkylation conditions.

There is description of a terminal, primary cation that would possibly cyclize to the indan structure.[44] The 2,2-dimethyl-3-phenyl-1-propenyl system underwent methyl and benzyl migrations rather than cyclization to an indan as shown in Scheme XXVII. These facts and the behavior of 39 described in the previous paragraph suggest that olefin 39 cannot account for cyclized products from cyclialkylation reactions. Clearly 39 does not exhibit suitable behavior for consideration as an intermediate of the cyclialkylation reaction.

One olefin remained for consideration. When 42 was subjected to cyclialkylation conditions it cyclized smoothly to 6 and formed four dimeric products. Each of these dimers had the same retention time as an actual cyclialkylation product. Of the olefins examined as possible

Scheme XXVII

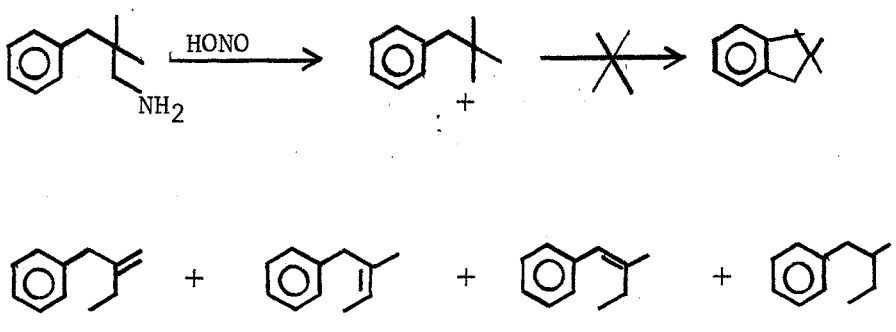
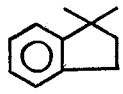
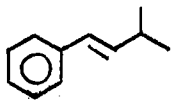
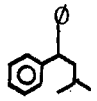
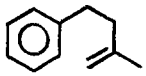
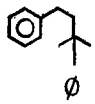
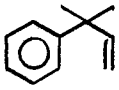
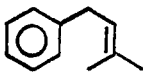
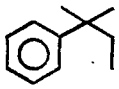
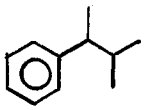
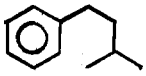
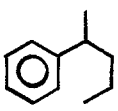


TABLE II

EFFECT OF SULFURIC ACID UPON SELECTED HYDROCARBONS

		Cyclohexane-H_2SO_4	Benzene-H_2SO_4
6		no reaction	no reaction
9		 , 6 dimers	  , 5 dimers
10		 , 2 dimers	  , 5 dimers
39		 , 4 dimers	 , 4-224 mol wt, 4 dimers
42		 , 4 dimers	 4 dimers
		no reaction	no reaction
		no reaction	no reaction
		no reaction	no reaction
		no reaction	no reaction

intermediates of the cyclialkylation reaction, 42 exhibited the most compatible behavior. Formation of this olefin as a cyclialkylation intermediate is in accord with currently accepted behavior of allylic electrophiles in the presence of an aromatic nucleus. Deno has found that alkyl substitution at the terminal carbon of the allyl system imparts additional stability to the resonance hybrid.[45,46,47]

Thus concerning benzene-isoprene cyclialkylation, it is postulated that presence of a methyl group at C-2 in the 1,3-butadiene molecule contributes stability to the allylic electrophile formed in sulfuric acid. Apparently the stabilized resonance hybrid which attacks as an electrophile must largely resemble the canonical form 37b to produce the products isolated from isoprene-arene cyclialkylation reactions. From the data reported herein it is concluded that pathway A of Scheme XXI is the predominant route to formation of cyclic products in the cyclialkylation reactions with sulfuric acid.

That an electrophile resembling 37b does indeed attack the arene system is substantiated by the presence of major amounts of 15 in the benzene-isoprene cyclialkylation products. Attack of this electrophile would produce the olefin 1,1,7,7-tetramethyl-4-(3-methyl-2-butenyl)-s-hydrindacene. Protonation of this olefin followed by hydride transfer to the resulting cation would give 15. In addition, other publications describe attachment of the 3-methyl-2-butenyl group to various aromatic systems in cyclialkylation-type reactions.[36,37,48,49,50,51,52]

CHAPTER IV

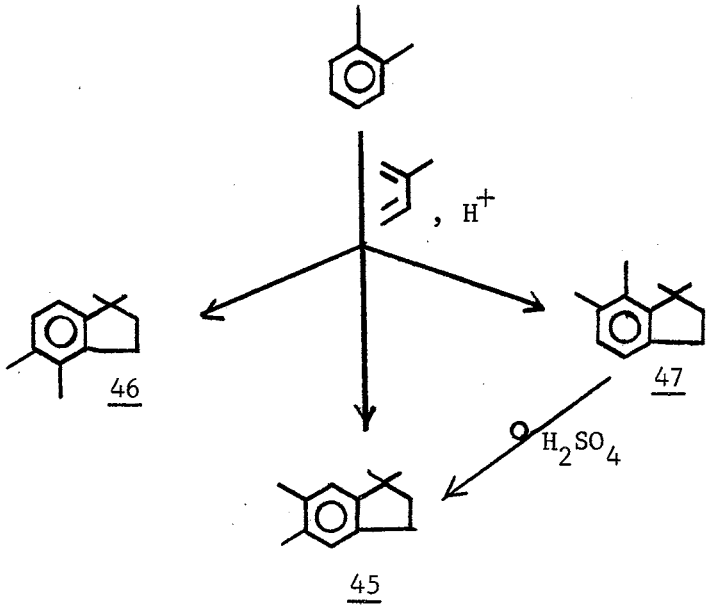
STABILITY OF CYCLIALKYLATION PRODUCTS

Once the indan structure had formed in the cyclialkylation reaction, it was of interest to determine its stability to acidic conditions. Previously it had been found that aluminum chloride will cause rearrangement of indans.[4a,4b,53]

Several systems were conveniently available for study. These were the indans obtained from cyclialkylation of o-xylene and tert-butylbenzene with isoprene.[4]

Cyclialkylation of o-xylene with isoprene[4] typically gives 1,1,5,6-tetramethylindan (45), 1,1,4,5-tetramethylindan (46), and 1,1,6,7-tetramethylindan (47) in the ratio 5:1:3 as shown in Scheme XXVIII. It was found that prolonged stirring of mixtures of 45, 46, and 47 with concentrated sulfuric acid at room temperature caused the gradual disappearance of 46 and 47. To determine whether the disappearance of the two isomers was due to sulfonation or rearrangement to 45, treatment of pure 46 and pure 47 with 97% sulfuric acid was followed by glc analysis. Gradual appearance of a small glc peak having the same retention time as 45 whenever 47 was thus treated suggests that 47 undergoes slight rearrangement. Hydrocarbon 46 gradually disappeared when similarly treated, but did not give glc evidence for formation of other products.

Scheme XXVIII



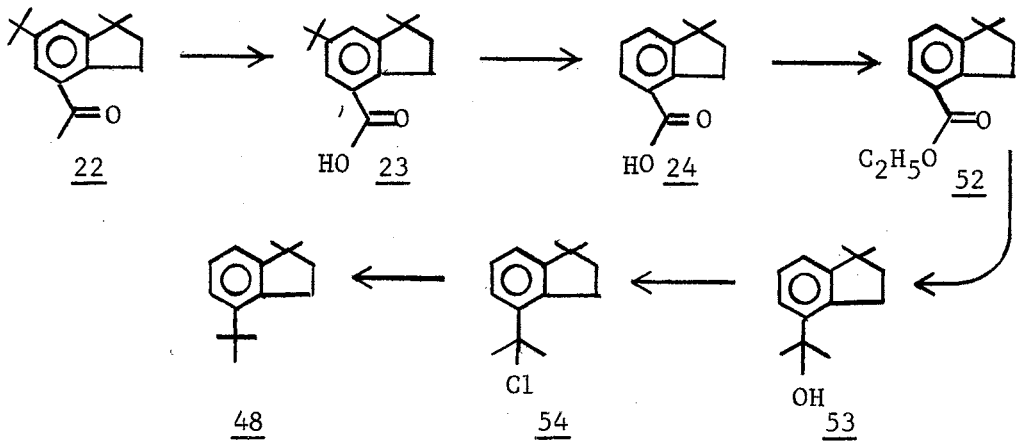
The "red oil" from sulfuric acid treatment of the original isomeric mixture was desulfonated by steam distillation from aqueous acid. Since all three isomers were recovered in good yield from this desulfonation, it was concluded that indans mainly sulfonate rather than rearrange. Isomer 46 was recovered from the desulfonation treatments in greater relative abundance than originally present. This suggests 46 sulfonates more readily and undergoes less rearrangement than 45 and 47. Isomer 47 was recovered in a much reduced concentration (relative to the other recovered material) after desulfonation. This is consistent with the suggestion that 47 rearranges to 45 and thereby yields less 47 in the desulfonation product. Other protonic catalyst systems such as trifluoroacetic acid, methanesulfonic acid, and Amberlyst-15 solid acid resin failed to affect the indans over a wide range of temperatures (25-140°), acid concentrations, and reaction durations. It

was concluded that the indan ring was essentially inert to proton catalysts.

What deductions could be made about stability of the indan ring substituents? Cyclialkylation of m-xylene with isoprene resulted in the formation of two hydrindacenes.[4b] These seem to result from intramolecular migration of a methyl group to an adjacent position. Such migration allows cyclization of the reaction intermediates to form hydrindacenes. Thus the formation of the indan structure is a strong driving force in the reaction. This force is large enough to cause methyl migration, perhaps by a Jacobsen-type shift.[54] In any event the ring substituents appear labile to some extent under the reaction conditions.

Another question of substituent stability arose in the cyclialkylation of tert-butylbenzene (35) with isoprene. The reaction was originally reported to yield 4-t-butyl-1,1-dimethylindan (48) and 1,4-di-t-butylbenzene (49) as minor products and 6-t-butyl-1,1-dimethylindan (50) as the major component.[4c,55] Reexamination indicated that instead of 48, 5-t-butyl-1,1-dimethylindan (51) probably was the minor isomer present. To resolve this question, 48 was independently synthesized by the route shown in Scheme XXIX. Carboxylic acid 24 (see Scheme XIII) was esterified by treatment with sulfuric acid and ethanol to give ethyl 1,1-dimethylindan-4-carboxylate (52) which was dropped into an excess of methylmagnesium chloride to produce 1,1-dimethyl-4-(1-hydroxy-1-methylethyl)indan (53). The alcohol was stirred with hydrochloric acid to give 1,1-dimethyl-4-(1-chloro-1-methylethyl)indan (54) which was refluxed with methylmagnesium chloride solution to yield 48.

Scheme XXIX



Once an authentic sample of 48 became available, it was readily shown that it was not present in the crude cyclialkylation mixture. Instead, 51 was identified as the minor isomer (2%). As discussed earlier, slight amounts of 40 were also isolated. The absence of the 4-alkyl substituted 48 was anomalous when compared to the results from other cyclialkylation reactions.[4c] Indeed the misassignment of 48 as the minor isomer was based in part on the lack of 5-alkyl-substituted indans in a series of cyclialkylations. Solely the 4- and 6-substituted isomers were formed in these reactions.[4c]

Did the isomeric distribution of 50 and 51 result entirely from steric inhibition to attack at the 4-position? Possibly 48 was initially formed but was reversibly destroyed or converted rapidly to 50 or 51, and thus not observed as a final product.

To test this possibility, each of the isomers 48, 50, and 51 was stirred with 97% sulfuric acid in the presence of benzene at room temperature. The glc analysis showed that 48 was converted to a mixture of 35, 6, 49, 51, 50, 48 in relative amounts of (31:26:1:2.3:2.5:26)

in order of emergence from a UC W-98 glc column. In similar experiments 50 and 51 were observed to give 35, 6, 49, 51, and 59 but 48 was not observed. Figure 6 depicts the glc analyses of the mixtures resulting from individual treatment of the isomers with sulfuric acid.

Thus all three isomers were found to be nearly equally stable to 6-14 hours contact with stirred sulfuric acid. This behavior of 48 strongly suggests that it was not formed in the cyclialkylation reaction and then disappeared. The t-butyl group was found to be labile but the lability was not the cause for the absence of 48 in cyclialkylation.

A likely cause for the absence of 48 in cyclialkylation reaction mixtures is that the isoprenoid electrophile is sterically prohibited from attachment at the ortho position of 35. Considerable steric strain is present in the cyclic molecule 48 as is evidenced by the nmr proton shifts of 48 relative to those of the isomeric 50 and 51. Thus the energy necessary to cause resonance of the t-butyl group protons is considerably increased in 48 and its ketone derivative. Table III lists the nmr proton shifts for the tert-butyl-1,1-dimethylindan isomers and their ketone derivatives.

In conclusion, these considerations show the indan ring to be fairly stable to sulfuric acid. But various conditions can cause inter- and intramolecular lability of the alkyl substituents about the aromatic portion of the indan ring. This is consistent with known behavior of alkyl aromatic compounds.

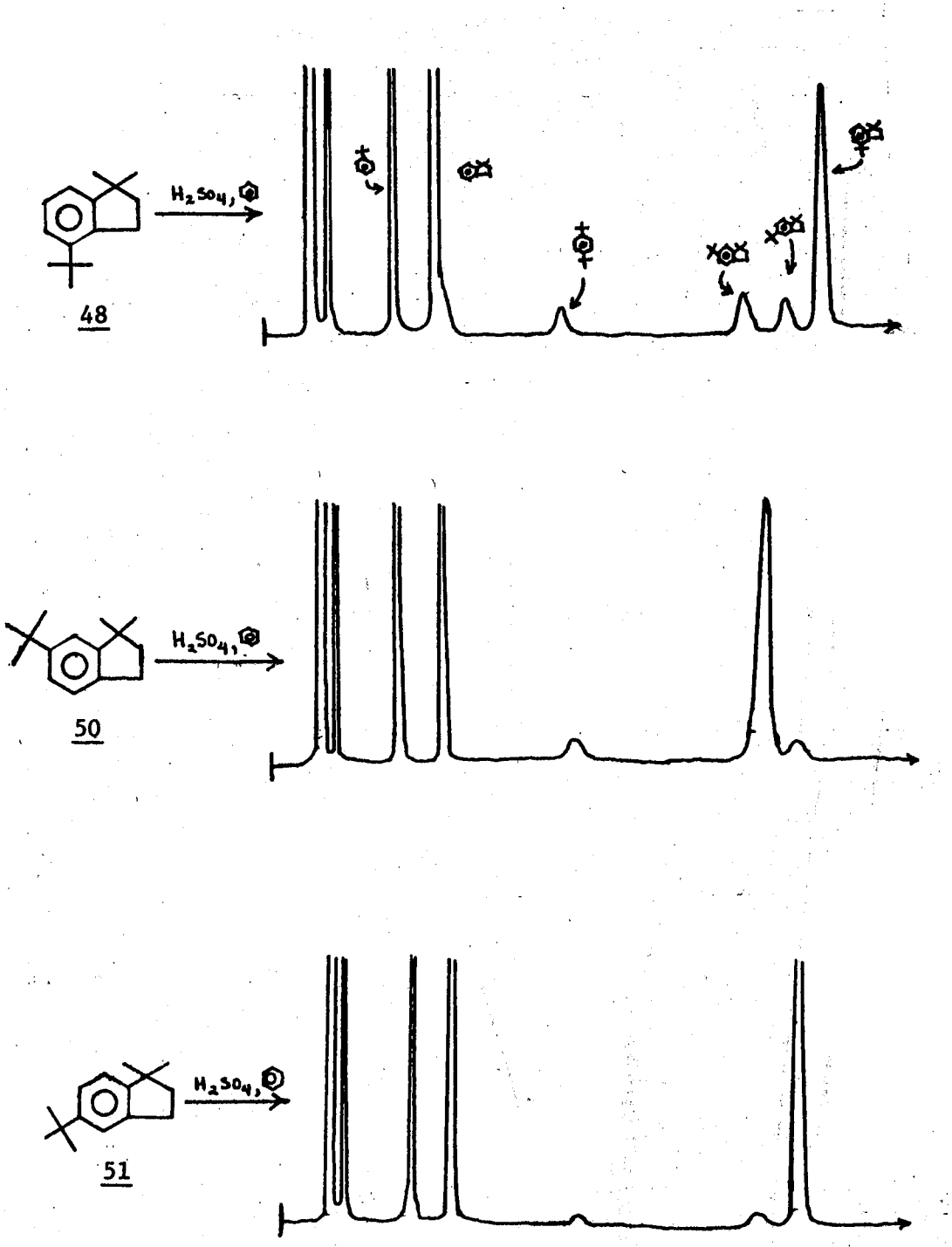
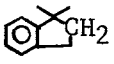
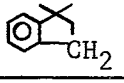
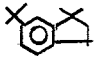
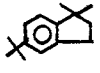
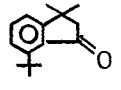
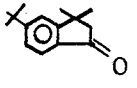
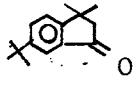


Figure 6. Glc Results of Sulfuric Acid Treatment of the tert-Butyl-1,1-Dimethylindans

TABLE III

PROTON SHIFTS OF THE TERT-BUTYL-1,1-DIMETHYLINDAN ISOMERS AND OXO DERIVATIVES

		Gem-Methyls	tert-Butyl			ArH	mp or bp
48		1.21	1.35	1.83	3.01	6.77-6.99	82° (0.15 mm)
50		1.22	1.28	1.87	2.78	6.94	87° (2 mm)
51		1.21	1.27	1.86	2.82	6.76-7.10	100-1° (4 mm)
		1.36	1.41	2.46	-	7.17-7.32	75° (0.1 mm)
		1.40	1.35	2.42	-	7.32-7.39	49-51°
		1.39	1.33	2.43	-	7.18-7.60	50-1°

CHAPTER V

OXIDATION

A convenient, quantitative method of preparing derivatives of cyclialkylation products was sought. The procedure should be applicable to crude cyclialkylation mixtures and the derivatives should be easily separable from unreacted and polymeric materials. Moreover, the derivatives should be conveniently separable from each other. It was recognized that the presence of benzylic methylene groups in the cyclic products made them especially suitable for oxidation. Oxidation of the mixtures of cyclialkylated products could also aid in separating them from large amounts of isoprene polymers present. These gummy polymers complicated purification by distillation and crystallization.

These isoprene polymers likely contained double bonds.[27,56] In view of this, ozone treatment of the reaction products was first attempted to destroy such polymers. This treatment, as expected, radically changed the composition of crude cyclialkylation mixtures. Figure 7 depicts the glc analyses of distillation fractions after ozone treatment and workup with basic peroxide and also after treatment of the ozonolysis products with a basic alumina chromatographic column. The starting material was a distillation fraction containing hydrindacenes and small amounts of higher-boiling products. Examination of the chromatograms showed that ozone oxidized the hydrindacenes

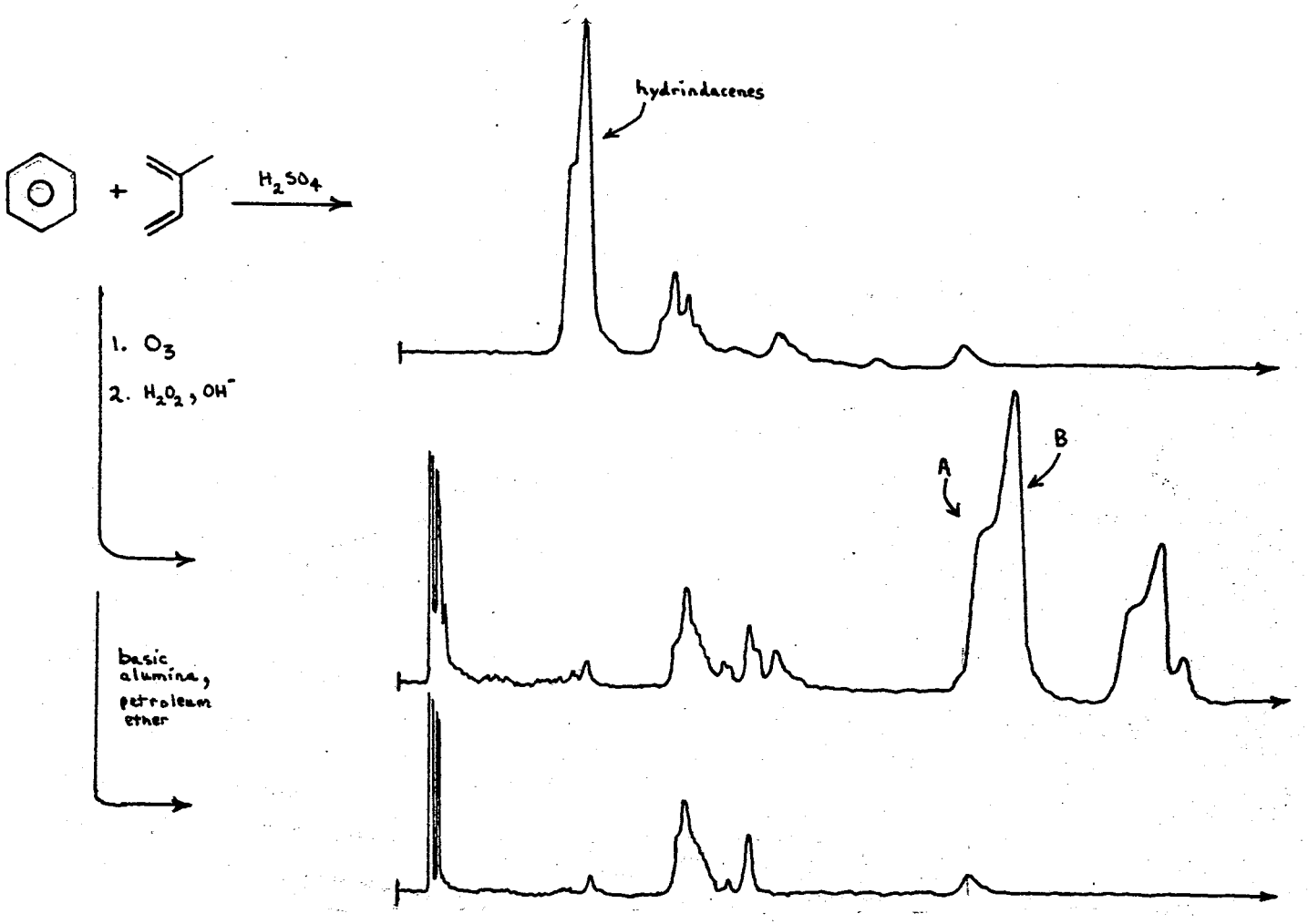


Figure 7. Ozone Treatment of Benzene-Isoprene Cyclialkylation Reaction Products

and polymers indiscriminately. The appearance of two large glc peaks after ozonolysis, labeled A and B in Fig. 7, implies formation of monoketones from the hydrindacenes that were initially present. The known monoketones show similar retention times. The compounds represented by glc peaks A and B were removed by column chromatography on basic alumina using petroleum ether[32] for elution. The complexity of ozonolysis products made it desirable to search for a more selective method.

Oxidation with basic permanganate is an established method of altering organic materials. Excessive oxidation was an expected limitation. A current modification indicated that permanganate oxidation of hydrindacenes to hydrindacenones could possibly be regulated by using a phase transfer catalyst.[57] However, 6 was inert to this procedure.

Recently a selective oxidation technique using the persulfate ion was described.[58] When 6 was subjected to this treatment, it was partially consumed but multiple oxidation products resulted. Figure 8 shows some of the reaction products as detected by glc analysis.

Chromic acid oxidation techniques have been used widely in preparing ketones. Several of these were tried.

Organic Syntheses describes a procedure using chromic anhydride, acetic acid, and sulfuric acid.[59] When 1,1,4,7,7,8-hexamethyl-s-hydrindacene (56) was subjected to this procedure, a mixture of solid products resulted. After glc comparison to known samples and ir analyses of the isolated products, it was concluded that the mixture consisted of a disheartening array of monoketones, diketones, anhydrides, various acetates, and unreacted 55.

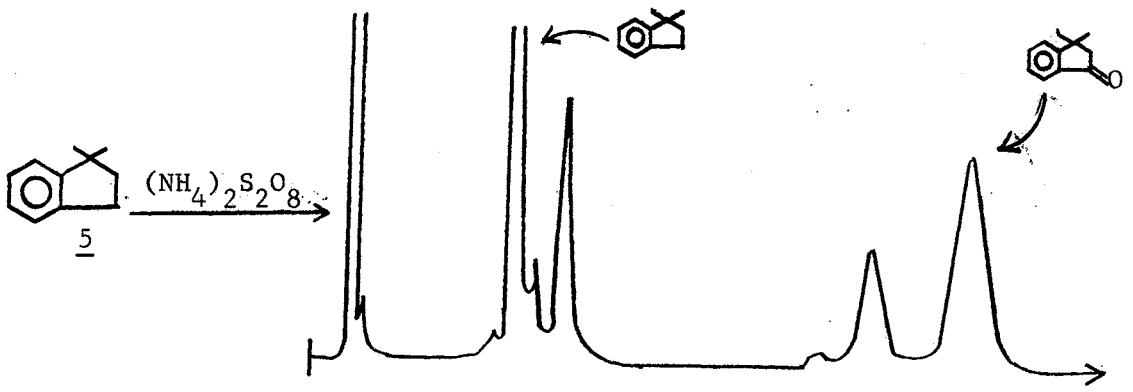


Figure 8. Persulfate Oxidation of 1,1-Dimethylindan (6)

When a modification of the above conditions, using cyclohexane as a solvent and water as diluent, was used to oxidize 55, nearly 90% of the starting material remained unconsumed. Similar results were obtained from treatment of 55 with sodium dichromate as described by a second Organic Syntheses method.[60]

Kuhn-Roth chromic acid reagent[61] with cyclohexane as a cosolvent could be used to oxidize mixtures of crude cyclialkylation products. The results were very similar to those of ozone treatment of the same mixtures. The workup is less convenient in the latter case. Hydrindacenones resulting from the Kuhn-Roth oxidation were easily distilled and partially separated by preparative glc. It was possible to obtain pure 18 and 19 by this method. The other isomeric hydrindacenones were not obtained pure. The described procedures gave low yields as a result of either too little or excessive oxidation. In addition, complex mixtures of products resulted which were difficult to separate.

A more selective, high-yield oxidation was needed. Eventually a technique was developed which gave high yields of monooxo derivatives of the hydrindacenes, a simplified workup, and easy isolation of the

products, provided the reaction temperature was maintained between 20-30°, sufficient acetic acid was used, and the chromic anhydride was added as a 10% solution in aqueous (5%) acetic acid. When these criteria were followed, the results shown in Table IV were obtained.

The following comments about these modifications are appropriate. If the temperature exceeded 30°, the yield was lowered because of oxidation of the indan ring to dicarboxylic acids. These acids could be recovered from the alkali rinses of the extracted reaction products but were not completely characterized.

It had been noted that the concentration of the oxidizable hydrocarbon affected the completeness of oxidation.[62] Experimentation substantiated this. When 6 was oxidized in concentrated solution in acetic acid (0.14 mol of 6 / 1. of acetic acid), only 75% of 6 was consumed. A similar oxidation using more acetic acid (0.04 mol of 6 / 1.) gave complete oxidation of 6.

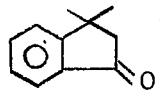
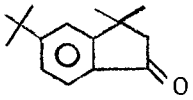
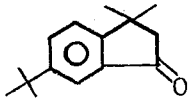
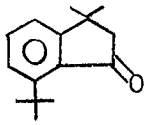
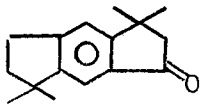
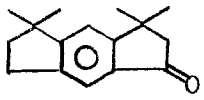
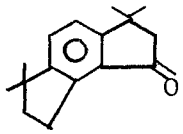
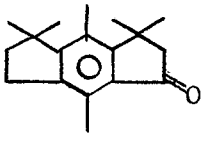
It was found that a relatively stable homogeneous 10% solution of chromic anhydride in aqueous (5%) acetic acid could be prepared. This homogeneous reagent was an effective, selective oxidizing agent for the benzylic methylene group of the indan ring.

The ketones obtained by this oxidative method were useful both as derivatives and as intermediates. As derivatives, they were more readily separated by preparative glc than the parent hydrocarbons. Once separated, the ketones could be converted back to hydrocarbons by hydrogenolysis.[63,64] As intermediates, they were potentially useful for preparing indenes by reduction to alcohols and dehydration.

The following description exemplifies the usefulness of the ketone derivatives for obtaining separate hydrindacene isomers.

TABLE IV

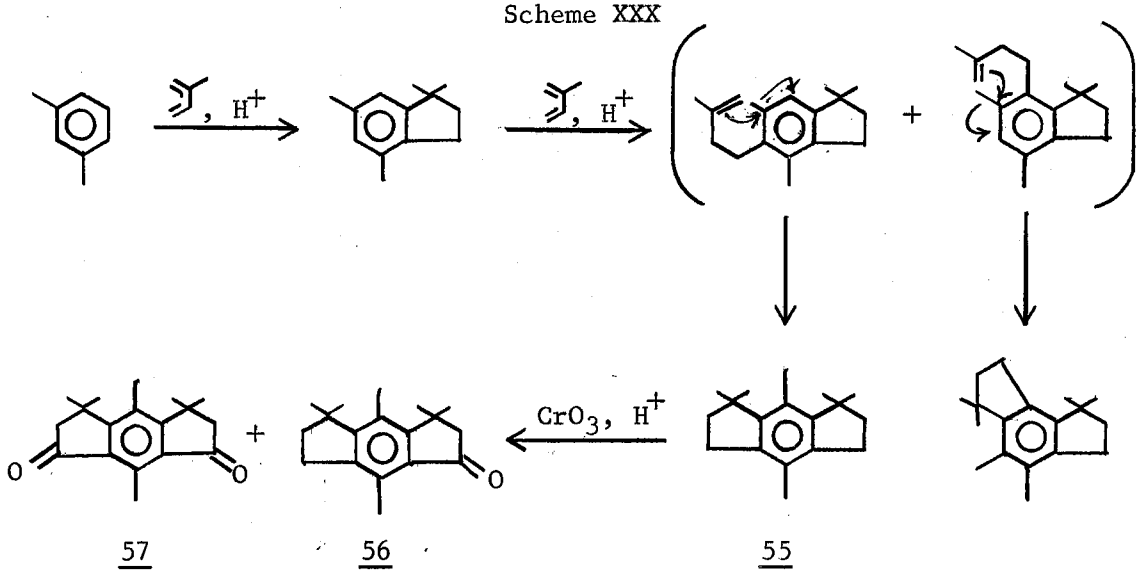
CHROMIC ANHYDRIDE OXIDATION PRODUCTS

	mp, °C	% Yield	% Calcd (Found) C	H
	bp 70 (0.2 mm)	88		
	50-51	87		
	49-51	92		
	bp 75 (0.1 mm)	86	83.29 (83.28)	9.10 (9.32)
	81-82	87	84.16 (84.30)	8.83 (8.76)
	98-99	90	84.16 (84.28)	8.83 (8.67)
	60-61	61	84.16 (83.99)	8.83 (8.81)
	186-88	88	84.32 (84.30)	9.44 (9.44)

Previous attempts[4] to separate pure 55 from the other cyclialkylation products of p-xylene with isoprene failed. The hydrindacene 55 is also available from the cyclialkylation of m-xylene as shown in Scheme XXX. Distillation of the m-xylene reaction products yielded a 9:1 ratio of $C_{18}H_{26}$ isomers with 55 predominating. Oxidation of this distillation cut, using 10% chromium trioxide in acetic acid, yielded a complex mixture of mono- and diketones from which 3,3,4,5,5,8-hexamethyl-s-hydrindacen-1-one (56) and 3,3,4,5,5,8-hexamethyl-s-hydrindacen-1,7-dione (57) were obtained (Scheme XXX) as a mixture by recrystallization from ether or petroleum ether.[32] Preparative glc was used to separate 56 and 57. Hydrogenolysis of the mixture of 56 and 57 afforded 55 as 99% pure hydrocarbon.

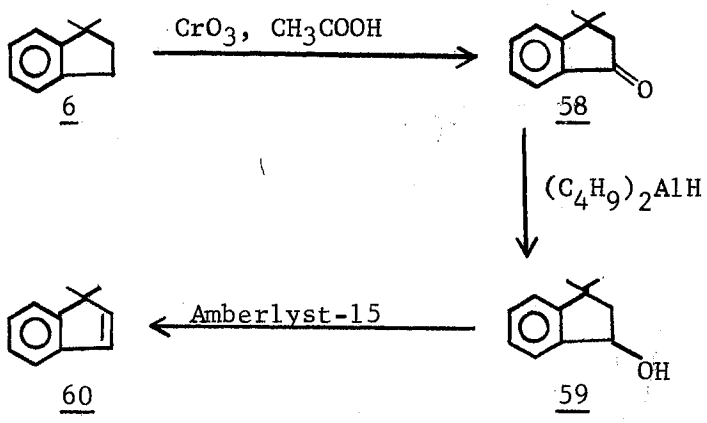
Indenes and their homologs are obtainable from these ketone derivatives as shown in Scheme XXXI. This was illustrated by the oxidation of 6 to 3,3-dimethylindanone (58) followed by reduction of 58 to 3,3-dimethyl-1-indanol (59). Dehydration of 59 was accomplished in

Scheme XXX



high yield using Amberlyst-15 sulfonic acid resin[65] in a technique developed for dehydration and cyclization.[29] By this sequence a 67% overall yield of 1,1-dimethylindene (60) was obtained.

Scheme XXXI



CHAPTER VI

EXPERIMENTAL

Mass spectra were obtained with a Consolidated Electrodynamics Corporation Model 21-110B high-resolution mass spectrometer operated under low resolution conditions using an electron energy of 70 eV. Nuclear magnetic resonance (nmr) spectra were obtained with a Varian Associates HR-60, HR-100, or A-60 spectrometer. Peak positions are reported in terms of δ = parts per million (ppm) downfield from internal standard tetramethylsilane ($\delta = 0$). Infrared spectra were obtained with a Beckman IR-5A spectrometer as films on sodium chloride plates or as potassium bromide pellets.

Melting points (mp) were taken in capillary melting-point tubes using a Thomas-Hoover apparatus and are corrected. Boiling points (bp) are uncorrected. The centigrade scale was used for all measurements.

Cyclohexane used in the reactions was "Baker Analyzed" Reagent Spectrophotometric quality. The benzene used was Fisher Certified Reagent (thiophene-free). Phillips pure grade isoprene was used in all cyclialkylation reactions. The sulfuric acid used was reagent grade.

Qualitative glc analyses were obtained with a Hewlett-Packard Model 5750 apparatus fitted with dual thermal conductivity and hydrogen flame detectors using helium as a carrier gas. Routine analyses were done with a variety of columns[66] and conditions. Quantitative glc

analyses were done on the same apparatus using a 12-ft x 0.25-in. column containing 5% silicone OV-101 on 80-mesh, dimethyldichlorosilane-treated, acid-washed Chromosorb G.[66a] For capillary analyses, a 200-ft x 0.02-in. stainless steel tube lined with Dow Corning 550 silicone oil[66b] was used on the glc apparatus described and the auxiliary flow feature of the Model 5750 instrument was utilized.

Samples for instrumental analyses were obtained by preparative glc using a F & M Model 700 gas chromatograph equipped with dual thermal conductivity detectors. Various columns[66] and conditions were used with this apparatus.

Crude samples of the cyclialkylation products from o-, m-, and p-xylenes with isoprene were prepared by J. R. Mattox. Selected purified samples of the resulting hydrocarbons were furnished by M. A. Wilhelm.

Cyclialkylation products derived from benzene-isoprene reactions were mainly prepared by J. W. LaFrentz and in part by L. R. Edmison.

Cyclialkylation of Benzene with Isoprene in the Presence of Sulfuric Acid.

Procedure A. To a 1-l., three-neck round-bottom flask, equipped with stirrer and dropping funnel and cooled in an ice bath, was added 234 g. benzene and 50 ml of 85% sulfuric acid. To the stirred mixture at 15° was added 68 g (1.0 mol) of isoprene in 117 g of benzene over 16 minutes. The temperature ranged from 15-20°. Stirring was continued for an additional 15 minutes and the product mixture was then transferred to a separatory funnel. The red-brown sulfuric acid layer was withdrawn and 30 ml of water was added to the funnel to quench the reaction. The benzene layer was washed with aqueous sodium carbonate

and 2 x 50 ml of water and dried ($MgSO_4$). This whole procedure was repeated 3 times and the combined benzene layers were distilled to give 15.5 g (3.5%) of 6: bp 73° (3 mm) (lit.[40] 189-191°); mass spectrum (70 eV) m/e (rel intensity) 146 (13), 132 (5), 131 (100), 116 (8), 115 (13), 91 (15); nmr (CCl_4) δ 7.05 (s, 4, ArH), 2.85 (t, 2, $ArCH_2$-), 1.88 (t, 2, $ArC(CH_3)_2\underline{CH_2}$-), 1.24 (s, 6, gem-$CH_3$).

A second run based on Procedure A was made with the scale increased twentyfold and the addition time increased from 16 to 135 min. The product mixture when distilled gave 100 g (2.3%) of 6 boiling at 80°(7 mm) and 305 g (9.5% of crude 7: mp 95-6° (lit.[11] 91-3°); mass spectrum (70 eV) m/e (rel intensity) 214 (15), 200 (17), 199 (100), 143 (24), 128 (8), 92 (10); nmr (CCl_4) δ 6.79 (s, 2, ArH), 2.79 (t, 4, $ArCH_2$-), 1.86 (t, 4, $ArC(CH_3)_2\underline{CH_2}$-), 1.21 (s, 12, gem-$CH_3$).

Anal. Calcd for $C_{16}H_{22}$: C, 89.65; H, 10.35. Found: C, 89.61; H, 10.40.

Other liquid fractions weighing 216 g (6.7%) distilled after 7 and a final fraction (178 g, 6%), bp 160-220°(1 mm), of mainly 13 was obtained. Recrystallization from 95% ethanol, acetone, and petroleum ether[32] and repeated chromatography on acidic alumina with petroleum ether[32] gave pure 13: mp 108-10°, mass spectrum (70 eV) m/e (rel intensity) 282 (20), 268 (76), 267 (100), 211 (24), 181 (9), 126 (11); nmr (CCl_4) δ 2.81 (t, 2, $ArCH_2$-), 2.69 (t, 4, $ArCH_2$-), 1.81 (t, 6, $ArCH_2\underline{CH_2}$-), 1.39 (s, 12, gem-CH3), 1.29 (s, 6, gem-CH_3).

Anal. Calcd for $C_{21}H_{30}$: C, 89.29; H, 10.71. Found: C, 89.50; H, 10.70.

Oxidation of 6.7 g (0.06 mol) of 13 in one 1. of acetic acid with 96 g of 10% CrO_3 solution yielded 5.2 g of filterable ketone products.

Ether extraction gave an additional 1.9 g of product. Preparative glc[66c] (260°, 50 cc/min) was used to isolate 30: mp 136-8°; ir (KBr) 1700 cm^{-1} (C=O); nmr (CCl_4) δ 2.73 (t, 4, $ArCH_2$-), 2.41 (s, 2, --CH_2CO-), 1.92 (t, 4, $ArCH_2\underline{CH_2}$-), 1.53, 1.45, and 1.40 (3s, 18, gem-CH_3).

Anal. Calcd for $C_{21}H_{28}O$: C, 85.08; H, 9.52. Found: C, 83.32; H, 9.42.

Procedure B. A 5-l., indented, round-bottom flask equipped with a dropping funnel, Lightnin XP stirrer, and turbine stirring paddle was cooled in a stirred ice-water-salt bath, and 1080 ml of benzene and 100 ml of 97% sulfuric acid were added. The stirrer was run until the temperature dropped to 15 . Isoprene (420 ml, 4 mol) diluted with 560 ml benzene was then added as rapidly as the temperature increase permitted (max 20). The total addition time was usually about 3-5 min. The stirrer was stopped and the flask contents were rapidly pumped with a Randolph model 610 pump into a 12-l. separatory funnel. After 10 min, the lower "red oil" layer was drained and the separatory funnel contents were then poured directly onto anhydrous sodium carbonate. The dried material was filtered, combined with that from other runs, and distilled to give 8.0, 7.2, and 13% of 6, 7, and 13, respectively.

Dehydration of 2-Methyl-4-phenyl-1-butanol (8) to 3-Methyl-1-phenyl-1-butene (9) and 2-Methyl-4-phenyl-1-butene (10). To a 100-ml two-neck flask equipped with heating mantle, Teflon-coated magnetic stirring bar, condenser, and thermometer were added 2 g of dried Amberlyst-15 (A-15) catalyst, 5 g of 14 and 50 ml cyclohexane. The temperature was raised to 65° and held for 80 min. The catalyst was removed by filtration and the mixture was distilled. A fraction

weighing 4.2 g (93%), bp 50-3° (0.4 mm), containing 9:10 (4:1) was collected. Preparative glc[66d] (70°, 30 cc/min) provided pure samples of 9 and 10. Comparison of the ir, nmr, and glc data of 9 and 10 with authentic samples established their structures.

Cyclodehydration of 8 to 1,1-Dimethylindan (6). To a 3-l., three-neck, round-bottom flask equipped with mechanical stirrer, Dean-Stark trap,[67] and an addition funnel were added 1.5 l. of distilled benzene and 25 g of dried A-15 catalyst.[65] The mixture was stirred and heated to the reflux temperature. A 32.8 g (0.2 mol) sample of 8 was added over 3 min and the mixture was heated under reflux for 2 hr, cooled and filtered. The filtrate was distilled through a 6-in. Vigreux column until the temperature rose above 80°. Distillation at 37-40° (0.7 mm) gave 22 g (75%) of 6: bp 190-1° (lit.[40] 189-91°).

Preparative GLC Purification of 1,1,7,7-Tetramethyl-s-hydrindacene (4) and 4-Isopentyl-1,1,7,7-tetramethyl-s-hydrindacene (15). A liquid tetramethylhydrindacene fraction subjected to preparative glc separation[30,66e] (160°, 50 cc/min) gave crystalline 4, recrystallized from acetone and then with cold ether: mp 60-1° (lit.[13] 45-7°); mass spectrum (70 eV) m/e (rel intensity) 214 (20), 200 (18), 199 (100), 143 (26), 41 (11), 29 (11); nmr (CCl_4) δ 6.84 (s, 1, ArH), 6.75 (s, 1 ArH), 2.76 (t, 4, $ArCH_2$-,), 1.85 (t, 4, $ArC(CH_3)_2\underline{CH_2}$-), 1.21 (s, 12, gem-$CH_3$).

Anal. Calcd for $C_{16}H_{22}$: C, 89.65; H, 10.35. Found: C, 89.56; H, 10.33.

The intermediate distillation fraction from benzene-isoprene cyclialkylation, bp 220-30° (0.2 mm), containing by glc analysis[66f] (270°, 25 cc/min) four major components, was dissolved in petroleum

ether[32] and flushed through layers of silica gel, basic alumina, and acidic alumina until a colorless solution was obtained. Concentration followed by preparative glc[30,66e] (200°, 50 cc/min) separated 15 from the mixture as a yellow oil with 10% impurity. Hydrocarbon 15 crystallized from the oil with difficulty. Upon recrystallization, 15 was obtained as waxy crystals: mp 46-7°; mass spectrum (70 eV) m/e (rel intensity) 284 (13), 270 (22), 269 (100), 243 (28), 241 (34), 229 (23); nmr (CCl_4) δ 6.58 (s, 1, ArH), 2.76 (t, 4, $ArCH_2$-), 2.40 (t, 2, $ArCH_2$-), 1.86 (t, 4, $ArC(CH_3)_2\underline{CH_2}$-), 1.63 (m, 1, -$\underline{CH}(CH_3)_2$), 1.45 (m, 2, $ArCH_2$-CH_2-$CH_2(CH_3)_2$), 1.20 (s, 12, gem-CH_3), 0.96 (d, 6, -$CH(\underline{CH_3})_2$).

Anal. Calcd for $C_{21}H_{32}$: C, 88.66, H, 11.34. Found: C, 88.71; H, 11.31.

A 0.6-g sample of 15 dissolved in 275 ml of acetic acid was oxidized with 8 g of a 10% CrO_3 solution. After dilution, 0.61 g of product was collected by filtration; this showed two glc peaks. Preparative glc[66c] (280°, 60 cc/min) was used to isolate 28 and 29: For 28; mp 84-6°; ir (KBr) 1697 cm^{-1} (C=O); mass spectrum (70 eV) m/e (rel intensity) 298 (20), 256 (20), 255 (100), 242 (50), 227 (53), 43 (16); nmr (CCl_4) δ 6.91 (s, 1, ArH), 2.96, 2.82 (t, 4, $ArCH_2$-), 2.41 (s, 2, $(CO)CH_2$-), 1.91 (t, 2, $ArCH_2\underline{CH_2}$-), 1.70 (m, 1, -$\underline{CH}(CH_3)_2$), 1.37 (s, 6, gem-CH_3), 1.35 (t, 2, $ArCH_2$-CH_2-$CH(CH_3)_2$), 1.27 (s, 6, gem-CH_3), 1.02, 0.92 (d, 6, $CH(\underline{CH_3})_2$); For 29; mp 194-5°, ir (KBr) 1695 cm^{-1} (C=O); mass spectrum (70 eV) m/e (rel intensity) 312 (28), 270 (23), 269 (100), 257 (17), 256 (87), 241 (42); nmr (CCl_4) δ 7.22 (s, 1, ArH), 3.30 (t, 2, $ArCH_2$-), 2.49 (s, 4, $-COCH_2$-), 1.70 (m, 1, -$\underline{CH}(CH_3)_2$), 1.42 (s, 12, gem-CH_3), 1.30 (t, 2, -$\underline{CH_2}$-$CH(CH_3)_2$), 1.01, 0.92 (d, 6, -$CH(\underline{CH_3})_2$).

Anal. Calcd for $C_{21}H_{30}O$: C, 84.51; H, 10.13. Found: C, 84.39; H, 10.30.

Anal. Calcd for $C_{21}H_{28}O_2$: C, 80.73; H, 9.03. Found: C, 80.63; H, 9.17.

Synthesis of 1,1,7,7-Tetramethyl-s-hydrindacene (4) and 1,1,6,6-Tetramethyl-as-hydrindacene (5). m-Bis(3-methyl-3-butenyl)benzene (3) was prepared[13] from 1,3-bis(chloromethyl)benzene and methallymagnesium chloride. Distillation of the product gave a 80% yield of 3: bp 95-9° (0.2 mm); nmr (CCl_4) δ 7.17-6.73 (m, 4, ArH), 4.70 (s, 4, vinylic CH_2), 2.82-2.52 (m, 4, $ArCH_2$-), 2.33-2.05 (m, 4, $ArCH_2CH_2$-), 1.67 (s, 6, $-CH_3$).

Cyclization was accomplished by adding 29 g of 3 to 120 ml of refluxing cyclohexane containing 5 g of dried A-15. Reflux was continued for 30 min, the mixture filtered and concentrated to give 28.3 of a 1:1 mixture of 4 and 5. A Nester-Faust Auto-Annular still was used to separate 4 from 5. An early fraction was collected at 42° (0.3 mm) and had a nmr spectrum identical to 4 obtained from cyclialkylation products. The fraction crystallized upon cooling. A late fraction containing 5 was collected which did not crystallize: bp 66° (0.3 mm) (lit.[13] 100-105°, 0.5 mm); nmr (CCl_4) δ 6.74 (s, 2, ArH), 2.75 (t, 4, $ArCH_2$-), 1.84 (t, 4, $ArCH_2CH_2$-), 1.27 (s, 6, gem-CH_3), 1.20 (s, 6, gem-CH_3).

Preparation and Reaction of o-Bis(3-Methyl-3-butenyl)benzene (20). Diolefin 20 was prepared by the method described for 3. Distillation of the product gave 5% of 20: bp 110-120° (0.1 mm); nmr (CCl_4) δ 7.02 (s, 4, ArH), 4.75 (s, 4, vinylic CH_2), 2.87-2.57 (m, 4, $ArCH_2$-), 2.35-2.10 (m, 4, $ArCH_2CH_2$-), 1.75 (s, 6, $-CH_3$). Cyclization as described

for 3 yielded a product which showed 7 glc peaks[66g] (220°, 45 cc/min). The major component (ca. 60%) was isolated by preparative glc[66d] (220°, 60 cc/min). Spectroscopy data were consistent with the structure of 21. Nmr analyses of the other major components, also obtained by preparative glc, excluded the presence of 11. For 21: nmr (CCl_4) δ 6.91 (s, 4, ArH), 6.13 (s, 1, vinylic CH), 2.68 (t, 2, $ArCH_2$), 2.15 (t, 2, $ArCH_2\underline{CH_2}$-), 1.76 (m, 1, $\underline{CH}(CH_3)_2$), 1.02 (s, 6, gem-CH_3), 0.85, 0.79 (d, 6, $CH(\underline{CH_3})_2$).

Synthesis of 3,3,6,6-Tetramethyl-as-hydrindacene (11). A 480-g (2.0 mol) sample of Celestolide (22) (international Flavors and Fragrances) was oxidized with NaOBr in dioxane.[15] The acidified product gave 453 g (93%) of crude 1,1-dimethyl-6-tert-butylindane-4-carboxylic acid (23). Recrystallization of a portion of crude 23 from petroleum ether[32] gave: mp 191-2° (lit.[15] 190 5-192°); nmr (CCl_4) δ 11.22 (s, 1, COOH), 7.84, 7.22 (s, 2, ArH), 3.23 (t, 2, $ArCH_2$-), 1.93 (t, 2, $ArCH_2\underline{CH_2}$-), 1.36 (s, 9, t-butyl), and 1.27 (s, 6, gem-CH_3).

A sample of 23 was esterified with CH_2N_2: nmr (CCl_4) δ 7.67, 7.12, (s, 2, ArH), 3.80 (s, 3, CO_2CH_3), 3.13 (t, 2, $ArCH_2$-), 1.89 (t, 2, $ArCH_2\underline{CH_2}$-), 1.32 (s, 9, t-butyl), 1.23 (s, 6, gem-CH_3). This product gave a single glc peak (240°, 30 cc/min.)[66f]

A mixture of 326 g (1.32 mol) of crude 23, 2.7-l. of toluene, and 730 g (5.5 mol) of $AlCl_3$ were stirred at room temperature for 19 hrs.[15] The reaction mixture was decomposed by stirring with ice and hydrochloric acid and then extracted with petroleum ether.[32] The organic layer was washed with 2 l. of 5% NaOH solution. Acidification and filtration yielded 232 g (92%) of crude 1,1-dimethylindan-4-carboxylic acid (24). Recrystallization from petroleum ether[32] gave 24: mp 145-6° (lit.[15]

145-147.6°); nmr (CCl_4) δ 12.43 (s, 1, COOH), 7.80 (m, 1, ArH), 7.80, 7.12 (s, 2, ArH), 3.29 (t, 2, $ArCH_2$-), 1.93 (t, 2, $ArCH_2\underline{CH_2}$-), 1.26 (s, 6, gem-CH_3).

A sample of 24 was esterified with CH_2N_2: mass spectrum (70 eV) m/e (rel intensity) 204 (26), 189 (100), 157 (36), 129 (33), 128 (28), 115 (30); nmr (CCl_4) δ 7.67 (m, 1, ArH), 7.12 (s, 1, ArH), 7.06 (d, 1, ArH), 3.78 (s, 3, $COOCH_3$), 3.20 (t, 2, $ArCH_2$-), 1.88 (t, 2, $ArCH_2\underline{CH_2}$-), 1.22 (s, 6, gem-CH_3). This product gave a single glc peak[66f] (240°, 30 cc/min).

Into a 5-l. flask equipped with Teflon-coated magnetic stirring bar, thermometer, addition funnel, reflux condenser, heating mantle, and nitrogen flush was placed 700 ml of dry benzene and 260 g of diisobutylaluminum hydride (DIBALH). The solution was heated to reflux and a solution of 76 g (0.4 mol) of 24 in 700 ml of benzene was added over 80 min. Reflux was continued 8 hrs before allowing the reaction mixture to cool. The products were poured onto ice, stirred, and the pH adjusted to ca. 3 with HCl. Ether extraction, drying ($MgSO_4$), and concentration yielded 65 g (93%) of crude 4-hydroxymethyl-1,1-dimethylindan (25): bp 100-1° (0.5 mm), lit.[68] 127-8°, 0.6 mm); mass spectrum (70 eV) m/e (rel intensity) 176 (22), 161 (100), 143 (59), 131 (36), 128 (27), 91 (27); nmr (CCl_4) δ 6.88 (s, 3, ArH), 4.28 (s, 2, $ArCH_2OH$), 3.84 (s, 1, OH), 2.70 (t, 2, $ArCH_2$-), 1.81 (t, 2, $ArCH_2\underline{CH_2}$-), 1.18 (s, 6, gem-CH_3).

In a small flask equipped with a sintered glass bubbling tube and an exit tube was placed 17.9 g (0.1 mol) of 25 and the contents were heated to 110°. Anhydrous HBr was slowly bubbled through the liquid with periodic shaking over 2 hr. The reaction mixture was poured into

water, stirred, and taken up in ether, and the ether layer dried ($MgSO_4$). Concentration gave 23.0 g of crude, lachrymatory, brown liquid. Distillation yielded 20 g (84%) of colorless 4-bromomethyl-1,1-dimethylindan (26): bp 110-13° (0.4 mm); nmr (CCl_4) δ 6.93 (s, 3, ArH), 4.30 (s, 2, CH_2Br), 2.87 (t, 2, $ArCH_2$-), 1.90 (t, 2, $ArCH_2\underline{CH_2}$-), 1.21 (s, 6, gem-CH_3).

Anal. Calcd for $C_{12}H_{15}Br$: C, 60.30; H, 6.33. Found: C, 61.38, H, 6.26.

Into a flask equipped with addition funnel, mechanical stirrer, condenser, and nitrogen flush was placed 5.3 g (0.22 mol) of magnesium turnings and 60 ml of ether. To this was added a crystal of iodine followed by 1 ml of redistilled methallyl chloride. While cooling with an ice bath, an additional 18 ml (0.16 mol) of methallyl chloride dissolved in 90 ml of dry ether was added over a 1-hr period. A gray slush resulted which was stirred at room temperature for 3 hr and then brought to reflux with heating. A solution of 19.8 g (0.083 mol) of 26 dissolved in 60 ml of ether was added during 1 hr. Reflux was continued for 4 hr. The reaction was cautiously decomposed with saturated NH_4Cl solution. The resulting mixture was ether extracted, the extract dried ($MgSO_4$) and condensed to give 16.1 g of yellow oil. Distillation yielded 6.6 g (38%) of colorless 4-(3-methyl-3-butenyl)-1,1-dimethylindan (27): bp 80° (0.2 mm); mass spectrum (70 eV) m/e (rel intensity) 214 (10), 199 (35), 159 (100), 158 (77), 143 (36), 129 (34), 128 (31); nmr (CCl_4) δ 6.80 (m, 3, ArH), 4.63 (s, 2, vinylic CH_2), 2.89 (t, 2, $ArCH_2CH_2C(CH_3)_2$), 2.82-2.05 (m, 4, $ArCH_2CH_2$-), 1.86 (t, 2, $ArCH_2CH_2C(CH_3)_2$), 1.73 (s, 3, $-CH_3$), 1.21 (s, 6, gem-CH_3).

Anal. Calcd for $C_{16}H_{22}$: C, 89.65; H, 10.35. Found: C, 89.61;

H, 10.33.

Cyclization of 2.7 g (0.012 mol) of 27 as described for 3 gave 2.6 g of crude 11. Recrystallization from cold methanol yielded 2.1 g (78%) of 11: mp 35-6°; mass spectrum (70 eV) m/e (rel intensity) 214 (15), 200 (18), 199 (100), 143 (26), 128 (11), 41 (10); nmr (CCl_4) δ 6.75 (s, 2, ArH), 2.72 (t 4, $ArCH_2$-), 1.89 (t, 4, $ArCH_2\underline{CH_2}$-), 1.22 (s, 12, gem-CH_3).

Anal. Calcd for $C_{16}H_{22}$: C, 89.65; H, 10.35. Found: C, 89.40; H, 10.51.

Synthesis of 1,1,4,4,7,7-Hexamethyltrindan (14). Into a 12-l., indented flask equipped with dropping funnel, Lightnin XP stirrer, turbine stirring paddle, thermometer, and nitrogen flush was placed 2.5 l. of dry benzene and 780 g (5.4 mol) of DIBALH. A slurry of 200 g (0.8 mol) of trimethyl-1,3,5-benzenetricarboxylate in 2 l. of benzene was added over 30 min to the stirred mixture. The temperature ranged from 20-62°. Stirring was continued for an additional 2 hr before quenching the excess DIBALH with ethyl acetate. Water (200 ml) was carefully added to the stirred reaction mixture. This was followed by cautious addition of 6 l. of technical grade methanol. The gelatinous mass that formed was stirred until it collapsed. Then it was gently warmed and left overnight. The organic layer was decanted and 3 l. of methanol added to the salt deposits. After stirring and settling of the mixture, the methanol layer was decanted. The process was repeated twice. The combined decanted layers were filtered using a Dicalite filter aid. Distillation of the organic solvents left 130 g of yellow gum. All but 6 g of the gum were dissolved by boiling with 80 ml of ethyl acetate and 5 ml of methanol. Petroleum ether[32] was added to the

solution until it clouded and then it was chilled overnight at -10°. The resulting white solid was filtered out. Several recrystallizations yielded 103 g (78%) of 1,3,5-tris(hydroxymethyl)benzene (31): mp 74-76° (lit.[69] 78-9°); nmr (D_2O) δ 7.11 (s, 3, ArH), 4.62 (s, -, DOH), 4.47 (s, 6, $-CH_2-$).

In a 25-ml flask equipped with Dean-Stark trap and fritted gas bubbling tube was placed 25.2 g (0.15 mol) of crude 31. The flask was immersed in an oil bath heated at 104°. With periodic shaking, anhydrous HBr was bubbled through the liquid for 5 hr. The cooled mixture solidifed and was then dissolved in 700 ml of ether. The ethereal solution was washed with 10% NaOH. Concentration gave 53 g (98%) of brownish 1,3,5-tris(bromomethyl)benzene (32). A small portion of this was recrystallized from petroleum ether[32] yielding white crystalline 32: mp 99-100° (lit.[69] 97-9°); nmr (CCl_4) δ 7.22 (s, 3, ArH), 4.34 (s, 6, $-CH_2$).

Into a 3-l. indented flask equipped with dropping funnel, mechanical stirrer, nitrogen flush, and condenser was placed 27.2 g (1.12 mol) of magnesium turnings and 300 ml of ether with a crystal of iodine. The flask contents were cooled with an external ice-salt bath and 10 ml of methallyl chloride added with stirring. An additional 80 ml (0.9 mol) of methallyl chloride dissolved in 500 ml of ether was added over a 2-hr period. The resulting gray slush was heated to reflux before a gray solution of 49 g (0.14 mol) of crude 32 in 400 ml of ether was added over 1.5 hr. Reflux was continued 3.5 hr before the reaction was treated with saturated NH_4Cl solution. The resulting mixture was filtered and extracted with ether. The ethereal layer was dried ($MgSO_4$) and concentrated which left 39 g of yellow oil. Glc

analysis[66f] (250°, 30 cc/min) indicated two major products were present. Distillation gave 5 g of an impure fraction consisting largely of 1-methyl-3,5-bis(3-methyl-3-butenyl)benzene: bp 98-121° (0.2 mm); mass spectrum (70 eV) m/e (rel intensity) 228 (24), 173 (100), 172 (36), 131 (29), 41 (24), 29 (26); nmr (CCl_4) δ 6.73 (s, 3, ArH), 4.62 (s, 4, vinylic CH_2), 2.90-2.03 (m, 8, $ArCH_2CH_2$-), 2.22 (s, 3, $ArCH_3$), 1.72 (s, 6, $-CH_3$). Also 7 g (18%) of 1,3,5-tris(3-methyl-3-butenyl)benzene (33) were obtained: bp 127° (0.2 mm); mass spectrum (70 eV) m/e (rel intensity) 282 (16), 227 (94), 226 (44), 171 (100), 129 (31), 41 (40), 29 (39); nmr (CCl_4) δ 6.67 (s, 3, ArHO, 4.63 (s, 6, vinylic CH_2), 2.78-2.05 (m, 12, $ArCH_2CH_2$-), 1.72 (s, 9, $-CH_3$).

Anal. Calcd for $C_{21}H_{30}$: C, 89.29; H, 10.71. Found: C, 89.37; H, 10.69.

Cyclization of 2.8 g (0.01 mol) of 33 as described for 3 gave 2.8 g of solid. Recrystallization from petroleum ether[32] yielded 2.0 g (67%) of 14: mp 238-9°; mass spectrum (70 eV) m/e (rel intensity) 282 (12), 268 (20), 267 (100), 211 (10), 166 (7), 29 (7); nmr (CCl_4) δ 2.82 (t, 6, $ArCH_2$-), 1.82 (t, 6, $ArCH_2CH_2$-), 1.25 (s, 9, gem-CH_3).

Anal. Calcd for $C_{21}H_{30}$: C, 89.29; H, 10.71. Found: C, 89.10; H, 10.56.

Isoprene Treatment of Hydrindacene Isomers and Other Hydrocarbons. To a 50-ml, indented, three-neck flask equipped with addition funnel, thermometer, and small Teflon-coated magnetic stirring bar was added 3 g of 97% H_2SO_4, 20 ml of trifluoroacetic acid, and 5×10^{-4} mol of reactive hydrocarbon dissolved in 3 ml of petroleum ether.[32] The mixture was rapidly stirred and cooled to 10°. A solution of 0.35 g (5×10^{-3} mol) of isoprene dissolved in 7 ml of petroleum ether[32] was

dropped in such that the temperature never exceeded 20°. The reaction was stirred for 15 min and then poured into 25 ml of petroleum ether[32] in a separatory funnel. The reaction flask was rinsed with a second portion of solvent which was combined with the first. The lower "red oil" sulfonic acid layer was removed and discarded. The organic layer was twice rinsed with 30 ml of water, once with 20% NaOH, and twice with saturated brine. Upon concentration, the organic product was directly injected on the glc column[66h] (250°, 30 cc/min) for analysis.

Isolation and Identification of tert-Butylbenzene (35). The combined benzene-isoprene cyclialkylation fractions containing 6 were purified by distillation.[70] One fraction (60 ml) recovered from the processing of 6 consisted of a component (ca. 70%) with a glc retention time longer than that for benzene and less than that for 6. Ozonolysis of the fraction removed one minor impurity (ca. 7%) which allowed isolation of 35 by preparative glc[66d] (80°, 40 cc/min). The ir, nmr, and mass spectra of the sample were identical to those of authentic t-butylbenzene.

Synthesis of 3-Methyl-3-phenyl-1-butene (39). Using the procedure of Dippy and Young,[71] 3-methyl-3-phenylbutyric acid (61) was prepared. Recrystallization from petroleum ether[32] gave white crystalline 61: mp 59-60° (lit.[71] 57-8°). To a flask equipped with mechanical stirrer, addition funnel, thermometer, nitrogen flush and reflux condenser was added 1.5 l. of dry benzene and 920 g (6.5 mol) of DIBALH. After bringing the solution to reflux a solution of 354 g (2.0 mol) of 61 in 2 l. of benzene was added over a 2-hr period. Reflux was continued for 4 hr. The reaction product was poured onto ice and the resulting

mixture adjusted to pH ca. 2 with HCl. Ether extraction, drying ($MgSO_4$), and concentration gave 280 g of crude 3-methyl-3-phenyl-1-butanol (41). The crude product contained a 2% impurity as shown by glc analysis. Distillation yielded 262 g (80%) of colorless 41: bp 130° (7 mm), (lit.[72] 137-8°, 16 mm).

A 100-ml sample of 41 was converted quantitatively to the acetate by dropping it into a refluxing benzene-acetic anhydride (3:1) solution. This crude solution was pyrolyzed over broken quartz at 510° under nitrogen atmosphere. Pyrolysis took 1 hr and gave a product that contained 65% of 39. Distillation yielded 39 with 5% impurity.[73] Preparative glc[30,66e] (140°, 35 cc/min)[66d] was used to obtain pure 39: bp 186-7° (lit.[74] 188°); nmr (CCl_4) δ 7.27-6.94 (m, 5, ArH), 5.92 (q, 1, ABX pattern for vinylic -C<u>H</u>=CH_2, J = 18), 5.05 (d, 1, vinylic CH_2), 4.80 (m, 1, vinylic CH_2), 1.30 (s, 6, gem-CH_3).

Isolation of p-tert-Butyl-tert-pentylbenzene (40). 20.2 g (0.1 mol) of distilled product from the cyclialkylation of 32 with isoprene[4b] was dissolved in 1.5 l. of acetic acid. To the stirred solution was added 288 ml of 10% chromic anhydride in acetic acid over 1 hr. The solution was stirred overnight, diluted with 4 l. of water, and extracted with petroleum ether.[32] The organic layers were rinsed with water and 20% NaOH. Drying ($MgSO_4$) and concentration left 21.5 g of orange oil. Glc analysis[66f] (200°, 30 cc/min) showed the oil consisted primarily of ketones plus a small amount (ca. 1-2%) of an unoxidized material. The mixture was distilled (99°, 0.35 mm) to concentrate the hydrocarbon. Preparative glc[66d] (175°, 40 cc/min) permitted isolation of an analytical sample of 40: ir 5.23, 5.41 μ (p-disubstituted);[75] nmr (CCl_4) δ 7.20 (s, 4, ArH), 1.63 (q, 2, -CH_2-), 1.30

(s, 9, $-C(CH_3)_3$), 1.26 (s, 6, gem-CH_3), 0.68 (t, 3, $-CH_3$).

Synthesis of 3-Methyl-1-phenyl-1-butene (9). To a 2-l. flask equipped with Teflon-coated magnetic stirring bar, nitrogen flush, addition funnel, and thermometer was added 500 ml of dry benzene and 250 g (1.74 mol) of DIBALH. Using external cooling, a solution of 90 g (0.55 mol) of isovalerophenone (Eastman Kodak) in 100 ml of benzene was added at a rate such that the temperature did not exceed 35°. The reaction mixture was poured onto a stirred mixture of ice and 20% HCl added until the pH was ca. 3. Ether extraction, drying ($MgSO_4$), and concentration gave 90 g of yellow oil. Distillation yielded 85 g (94%) of 3-methyl-1-phenyl-1-butanol (62): bp 200-1° (lit.[76] 120°, 20 mm); nmr (CCl_4) δ 7.05 (s, 5, ArH), 4.43 (t, 2, $-CH_2OH$), 3.76 (s, 1, OH), 1.53-1.13 (m, 3, $-CH_2CH-$), 0.88, 0.78 (d, 6, $CH(CH_3)_2$).

Dehydration of 14 g (0.85 mol) of 62 was accomplished by adding it to a refluxing mixture of 80 ml of benzene and 110 ml of formic acid. After 1 hr of reflux, an additional 60 ml of formic acid was added. Reflux was continued for 4 hr. The reaction mixture was poured into water, extracted with benzene, and the organic layer was washed with 10% NaOH, saturated brine, dried ($MgSO_4$), and concentrated to give an oil. Distillation of the oil yielded 4 g (32%) of 8: bp 204° (lit.[76] 101-3°, 20 mm); nmr (CCl_4) δ 7.09 (m, 5, ArH), 6.37-5.75 (m, 2, $-CH=CH-$), 2.57-1.94 (m, 1, $-CH(CH_3)_2$), 1.06, 0.95 (d, 6, $-CH(CH_3)_2$).

Synthesis of 2-Methyl-4-phenyl-1-butene (10). This olefin could be obtained from the dehydration of 8 by preparative glc. Commercial samples (Aldrich) were the preferred source.

Synthesis of 2-Methyl-4-phenyl-2-butene (42). Into a flask equipped with a Dean-Stark trap, Teflon-coated magnetic stirring bar, and thermometer was placed 210 g of Dimethyl Phenyl Ethyl Carbinol (International Flavors and Fragrances) and a crystal of iodine. With stirring the alcohol was heated. The temperature was held at 180° for 2 hr. The product was distilled and a 160-g fraction boiling at 45-52° (0.2 mm) was collected. Glc analysis indicated the fraction contained ca. 90% of 42 and 10% isomeric material. Preparative glc[30] (110°, 40 cc/min)[66i] (130°, 40 cc/min)[66d] yielded 70 g (38%) of 42: bp 208° (lit.[77] 81°, 12 mm); mass spectrum (70 eV) m/e (rel intensity) 146 (48), 131 (100), 129 (20), 91 (55), 51 (18), 39 (25); nmr (CCl_4) δ 7.09 (s,5 ArH), 5.28 (t, 1, -CH=C-), 3.33, 3.21 (d, 2, $ArCH_2$-), 1.70 (d, 6, $=C(CH_3)_2$).

Subjection of Olefin Intermediates to Cyclialkylation Conditions. Into a 50-ml, indented flask equipped with a small, Teflon-coated magnetic stirring bar and thermometer were placed 1 g (1×10^{-2} mol) of sulfuric acid and 2×10^{-1} mol of solvent. The solvent had been stirred with H_2SO_4 previous to use. Constant rapid agitation was achieved by use of a Variac-controlled magnetic stirrer. The flask was set in a fast-draining ice bath equipped with a motor and stirring shaft. The contents of the flask were cooled to 12° and a solution containing 0.73 g (5×10^{-3} mol) of olefin, 7×10^{-2} mol of solvent, and internal standards of 0.17 g (1×10^{-3}) mol of n-$C_{12}H_{26}$ and 0.14 g (5×10^{-4} mol) of n-$C_{20}H_{42}$ was added in one portion. When the temperature ceased to rise (ca. 22°) the ice bath was quickly drained and the reaction continued for a total of 60 min. Samples were taken at 2, 4, 10, 15, 20, 25, 40, and 60-min intervals, neutralized (20% NaOH),

extracted, and injected for glc analysis.[66a,78]

Isolation of 3-Methyl-1,1-diphenylbutane (43). When 9 or 62 were stirred with benzene in the presence of H_2SO_4, a product with glc retention time between that of 6 and dimer products (mol wt = 242) was formed (ca. 10-30%). Preparative glc[66c] (280°, 50 cc/min) gave a clear liquid identified as 43: bp 165-7° (1 mm), lit.[79] 305°); mass spectrum (70 eV) m/e (rel intensity) 224 (10), 168 (16), 167 (100), 165 (21), 91 (15), 41 (12); nmr (CCl_4) δ 7.10 (s, 10, ArH), 3.95 (t, 1, Ar_2CH-), 1.87 (q, 2, Ar_2CHCH_2-), 1.50-1.10 (m, 1, -$CH(CH_3)_2$), 0.96 0.87 (d, 6, -$CH(CH_3)_2$).

Sulfuric Acid Treatment of the o-Xylene-Derived Indans. A 2-l. wide-mouth separatory funnel was equipped with gas-tight head, addition funnel, thermometer, and Vibromixer was assembled. To this was added 800 ml of cyclohexane and 200 ml of a distilled mixture (bp 233-4°) of indans derived from cyclialkylation of o-xylene with isoprene. The mixture consisted of 45, 46, and 47 in the ratio 5:1:3. Sulfuric acid (400 ml) was added in 50-ml portions over a 24-hr period. A slight temperature rise (2°) was observed after each addition. Glc samples were withdrawn before each addition of acid and neutralized with Na_2CO_3 before analysis by glc. The sulfonic "red oil" layer was periodically drained off and saved. At the end of the reaction, the cyclohexane layer was neutralized (NaOH), concentrated, and distilled to yield 60 g of pure 45: bp 133° (0.1 mm).

Desulfonation of Sulfonic Acid Residues. A 11-g portion of the "red oil" described above was placed in a 300-ml flask with 150 ml of 70% H_2SO_4 and steam distilled. After ether extraction and concentration, 7.5 mo of product 45:46:47 (3:2:1) was recovered. Treatment of

the pure indan isomers with H_2SO_4 was performed in a manner similar to the above but on a reduced scale.

Synthesis of 4-t-Butyl-1,1-dimethylindan (48). A 130-g (0.68 mol) sample of 24 was prepared as described previously.[15] This acid was esterified with 95% ethanol (250 ml) in the presence of 10 ml of H_2SO_4 and 500 ml of benzene using a Dean-Stark trap to remove water during the azeotropic distillation. After 7 days of heating, the reaction mixture was cooled, ether and water were added, and the organic extract was dried ($MgSO_4$) and concentrated to 150 g of orange-colored oil. Distillation gave 147 g (98%) of ethyl 1,1-dimethylindan-4-carboxylate (52): bp 115° (0.5 mm); mass spectrum (70 eV) m/e (rel intensity) 218 (32), 203 (100), 131 (33), 129 (30), 128 (29), 15 (29); nmr (CCl_4) δ 7.67 (center of m, 1, ArH), 7.12 (s, 1, ArH), 7.07 (center of m, 1, ArH), 4.23 (q, 2, $-C\underline{H}_2CH_3$), 3.20 (t, 2, $ArCH_2-$), 1.88 (t, 2, $ArCH_2C\underline{H}_2-$), 1.35 (t, 3, $-CH_2C\underline{H}_3$), 1.22 (s, 6, gem-CH_3).

Anal. Calcd for $C_{14}H_{18}O_2$: C, 77.03; H, 8.31. Found: C, 76.89; H, 8.34.

To a 3-l., indented flask containing 750 ml (2.1 mol) of methylmagnesium chloride in tetrahydrofuran (THF) and equipped with mechanical stirrer and paddle, addition funnel, nitrogen flush, and reflux condenser was added a solution of 142 g (0.65 mol) of 68 in 400 ml THF over 80 min. This rate of addition maintained a reflux temperature. Reflux was continued by heating with a mantle for 5 hr. A saturated solution of NH_4Cl (400 ml) was added over 2 hr. The salts were filtered off and rinsed with ether. The filtrate was washed twice with saturated brine, dried ($MgSO_4$), and concentrated to 132 g (99%) of waxy white solid. Recrystallization from petroleum ether[32] gave

1,1-dimethyl-4-(1-hydroxyl-1-methylethyl)indan (53): mp 80-1°; mass spectrum (70 eV) m/e (rel intensity) 204 (2), 189 (43), 186 (43), 171 (51), 128 (15), 115 (15); 43 (100); nmr (CCl_4) δ 7.01-6.80 (m, 3, ArH), 3.02 (t, 2, $ArCH_2$-), 1.82 (t, 2, $ArCH_2\underline{CH_2}$- center on triplet overlapping with -O<u>H</u>), 1.82 (s, 1, OH), 1.48 (s, 6, gem-CH_3).

Anal. Calcd for $C_{14}H_{20}O$: C, 82.30; H, 9.87. Found: C, 82.16; H, 10.04.

A mixture of 1.5 l. concentrated HCl and 61 g of 53 was stirred overnight with an E-1 Vibromixer at room temperature. This mixture was extracted with 3 l. of ether in two portions. The extract was washed with water, 5% NaOH solution, saturated brine and then concentrated to remove most of the ether. THF (1 l.) was added and the volume was reduced to 500 ml and then dried (Na_2SO_4). A portion of the solution was concentrated under reduced pressure to remove THF and obtain an nmr analysis of 1,1-dimethyl-4-(1-chloro-1-methylethyl) indan (54), which did not exhibit vinyl absorption: nmr (CCl_4) 7.10-6.88 (m, 3, ArH), 3.12 (t, 2, $ArCH_2$-), 1.97 (s, 6, $-C(CH_3)_2)Cl$, overlapped with the following triplet), 1.88 (t, 2, $ArCH_2\underline{CH_2}$-), 1.23 (s, 6, gem-CH_3).

The dried crude alkyl chloride 54 in THF was used directly by adding it to a stirred and refluxing solution of 310 ml (0.9 mol) of methylmagnesium chloride in THF over a period of 2 hr. The Grignard reagent was contained in a 3-l. indented flask fitted with stirring paddle, nitrogen flush, reflux condenser and addition funnel. The stirred mixture was refluxed for 18 hr, cooled and cautiously decomposed with saturated NH_4Cl solution. The white salts were filtered, rinsed with ether and discarded. The filtrate was dried ($MgSO_4$) and

concentrated to give 53 g of yellow-colored oil. Distillation at 62-72° (0.2 mm) gave 45 g of a colorless mixture which showed three components in the glc trace. These were 4-isopropenyl-1,1-dimethylindan (63), 48, and an unknown (25:19:1) in the order of glc[66f] elution (210°, 30 cc/min).

A mixture of 33 g of 48 and 63 and 20 ml of benzene was added over 2 hr to a stirred mixture of 30 ml benzene, 4.2 g of Aliquat 336 (Quaker Oats), and 94 g of $KMnO_4$ in 75 ml water held at 40-55°. Close attention is required during addition since there appears to be a time lag in temperature rise. After stirring at 60° for three hr, the reaction mixture was filtered through Dicalite to remove MnO_2. This cake was rinsed with petroleum ether.[32] The organic filtrate was dried ($MgSO_4$) and concentrated to give 31 g of red oil shown by glc to contain 48, 4-acetyl-1,1-dimethylindan (64), and unknown (12:7:1) in the order of glc elution.[66f] The water layer of the filtrate was acidified and extracted with ether but the extract gave negligible residue.

A 15-g mixture of crude 48:64 (1:1.3), 15-g of Girard's T reagent, 15 ml of acetic acid and 150 ml of 95% ethanol were stirred at reflux for 12 hr. The reaction mixture was cooled, added to 1 l. of water and then extracted with three 400-ml portions of petroleum ether.[32] The extract was dried ($MgSO_4$) and concentrated to 6.2 g of oil. Distillation gave 4 g of 48: bp 60-1° (0.1 mm); mass spectrum (70 eV) m/e (rel intensity) 202 (16), 188 (15), 187 (100), 131 (14), 57 (44), 41 (13); nmr (CCl_4) δ 6.98-6.78 (m, 3, ArH), 3.01 (t, 2, $ArCH_2$-), 1.82 (t, 2, $ArCH_2\underline{CH_2}$-), 1.34 (s, 9, $-C(CH_3)_3$), 1.21 (s, 6, gem-CH_3).

Anal. Calcd for $C_{15}H_{22}$: C, 89.04; H, 10.96. Found: C, 89.24; H, 11.06.

The aqueous layer was mixed with 50 ml of concentrated HCl and heated on the steam bath under a reflux condenser for 4 hr. The reaction mixture was cooled, extracted with petroleum ether[32] and the extract was dried ($MgSO_4$) and concentrated to an oil. Distillation gave 2.1 g of 64: bp 82° (0.15 mm); ir (C=O) 1680 cm^{-1}; mass spectrum (70 eV) m/e (rel intensity) 188 (33), 173 (54), 129 (9), 128 (9), 115 (13), 43 (100); nmr (CCl_4) δ 7.48 (m, 1, ArH), 7.13 (s, 1, ArH), 7.01 (m, 1, ArH), 3.16 (t, 2, $ArCH_2$-), 2.46 (s, 3, -$COCH_3$), 1.87 (t, 2, $ArCH_2CH_2$-), 1.22 (s, 6, gem-CH_3).

Anal. Calcd for $C_{13}H_{16}O$: C, 82.93; H, 8.57. Found: C, 84.08; H, 9.54.

Sulfuric Acid-Catalyzed Isomerization of 4-t-Butyl-1,1-Dimethylindan (46). A 0.3-g sample of 48 was added to a rapidly stirred mixture of 4 g of sulfuric acid and 7 ml of benzene. At intervals over 6 hr, stirring was stopped and 0.5-ml samples of the organic phase were withdrawn. These samples were neutralized by shaking with 20% NaOH solution and then analyzed by glc[66h] (179°, 30 cc/min) which showed 3.75, 5.25, 9.40, 12.5, 13.7, and 14.6-min retention times for 35, 6, 49, 50, 51, and 48 respectively in the following ratio of peak areas 31:26:1:2.5:2.3:26.

In similar experiments of 14-hr duration, 50 and 51 were isomerized with H_2SO_4. The glc[66h] showed that 35, 6, 49, 51, and 50 were present but none of 48 was observed in the final product mixture. The ratios of products formed from 50 and 51 were 21:15:1:22:1.8 and 25:20:1:1.3:77.

Ozonolysis of Hydrindacene Fractions. Into a 1-l. flask equipped with a gas bubbling tube and mechanical stirrer was placed 40 g of a

distillation fraction containing primarily hydrindacenes (bp 110°, 0.2 mm) and 350 ml of methylene chloride. The flask was surrounded by a Dry Ice-acetone bath. Oxygen containing ozone was bubbled through the stirred solution (0.16 SCFM) for 6 hr. The light-green solution was then poured into a stirred solution of 250 ml of 10% NaOH and 150 ml of 30% H_2O_2. The methylene chloride layer was separated, washed with a $FeSO_4$ solution, 10% HCl, and water. The layer was dried ($MgSO_4$) and concentrated to give 27 g of orange oil. The orange oil was dissolved in 500 ml of petroleum ether[32] and passed through 50 g of basic alumina. An 8-g fraction of yellow oil remained after evaporation of the solvent. This fraction was conspicuously free of the material which exhibited long glc retention times. The alumina layers could be washed with acetone and the acetone evaporated to recover this oxidized product.

Permanganate Treatment of 1,1-Dimethylindan (6). The oxidation procedure[57] for 1-decene was followed with substitution of 21.9 g (0.15 mol) of 6 for the alkene and reducing the quantity of all reagents by 1/4. Heating was required to maintain a temperature of 40°. The reaction mixture was kept at this temperature for 10 hr, diluted with water, and then steam distilled. The distillate contained 6 and ca. 2% of an unidentified product when analyzed by glc.

Persulfate Treatment of 1,1-Dimethylindan (6). The described procedure[58] was followed but 14.6 g (0.1 mol) of 6 was substituted for ethylbenzene and the quantity of all reagents was halved. The reaction was heated at 65-75° for 4 hr. Glc analysis indicated that the product consisted largely of 6 and give other products.

Chromic Acid Oxidations of 1,1,4,7,7,8-Hexamethyl-s-Hydrindacene (55). Following an Organic Syntheses procedure[59] 121 g (0.5 mol) of 55, 1.6 l. of acetic acid, 1.6 l. of acetic anhydride, and 236 mol of H_2SO_4 were placed in a flask. With stirring and cooling (5-8°), CrO_3 (278 g, 1.84 mol) was added over 1.3 hr. The reaction mixture was stirred for 2 hr and then added to ice. A solid product (90 g) was filtered from the aqueous mixture. After hydrolysis of the solid, partial separation and analysis showed the product consisted of an intractable mixture of 55, 56, 57, acetates, and anhydrides.

Into a flask fitted with reflux condenser were placed 2 g of 55, 10 ml of cyclohexane, 40 ml of acetic acid, 50 ml of water and 5 g of CrO_3. The mixture was heated at reflux for 26 hr. It was then diluted with water and extracted with ether. After concentration a 1.6 g product consisting of 9:1 mixture of 55:56, was obtained.

To a 5-l. flask were added 850 ml of acetic acid, 1 l. of benzene, 121 g (0.5 mol) of 55, and 3 g of $CeCl_3.7\ H_2O$.[60] With rapid stirring 200 g (0.66 mol) of $Na_2Cr_2O_7$ were added over 9 hr with the temperature kept below 36°. The benzene layer was isolated and condensed to give 115 g of solid product. Glc analysis indicated the product consisted of 55 and 56 (9:1).

Kuhn-Roth Oxidation of Hydrindacene Mixtures. To a 5-l. flask equipped with E-1 Vibromixer was added 1 l. of Kuhn-Roth reagent,[61] 150 g of a hydrindacene distillation fraction (bp 110° 10.2 mm) of the crude cyclialkylation mixture, and 1 l. of cyclohexane. The mixture was agitated at reflux for 48 hr. The cyclohexane layer was isolated, rinsed with water and then 10% NaOH, and concentrated to give 80 g of material. Glc analysis showed the product to consist largely of

mono- and diketone derivatives of the hydrindacene isomers.

10% Chromic Anhydride Oxidation Procedures:

General Conditions of the Reaction. A sample of the hydrocarbon (1 to 15 g) is dissolved in 1 l. of acetic acid, with heating if necessary. A 10% solution of CrO_3 is introduced to the magnetically stirred solution through an addition funnel at a rate such that the reaction temperature remains below 30°. The 10% CrO_3 solution is prepared by mixing 190 ml of acetic acid, 10 ml of water, and 21 g of CrO_3 until a homogeneous solution is formed. Best results were obtained by using twice the stoichiometric amount of 4/3 mol of CrO_3 per methylene group.

The reaction mixture is stirred overnight and then diluted with six volumes of water. The mixture is extracted with ether or petroleum ether[32] or filtered, depending upon the physical properties of the product monoketone. The following procedures are illustrative.

Oxidation of 1,1-Dimethylindan (6) to 3,3-Dimethyl-1-Indanone (58). To a stirred mixture of 5.85 g (0.04 mol) of 6 dissolved in 1 l. of acetic acid, was added 107 ml of 10% CrO_3 solution over a 30-min period. The reaction temperature remained below 30°. The solution was stirred overnight, diluted with 5 l. of water, and extracted with two 1-l. portions of petroleum ether.[32] The combined organic extract was washed with 10% NaOH, dried ($MgSO_4$), and concentrated by distillation. This procedure gave 6.0 g of orange-colored oil. Distillation gave 5.6 (88%) of colorless 58: ir (C=O) 1709 cm^{-1}; nmr (CCl_4) δ 7.59-7.05 (m, 4, ArH), 2.44 (s, 2, $-COCH_2-$), 1.40 (s, 6, gem-CH_3).

3,3-Dimethyl-1-indanol (59). To a flask equipped with Teflon-coated magnetic stirring bar and a thermometer, was added 400 ml of dry benzene and 29 g (0.2 mol) of DIBALH. The flask was immersed in cold

water and a solution of 24 g (0.15 mol) of crude 58 in 400 ml of benzene was added over 20 min. Stirring was continued for an additional 20 min and then the reaction was poured onto ice. The pH of the mixture was adjusted to ca. 4 by addition of 15% HCl. The mixture was extracted with three 600-ml portions of ether, and the combined ether extract was washed with 10% NaOH and dried ($MgSO_4$). Evaporation left 24 g of yellow oil. Distillation gave 22.5 g (94%) of 59: bp 71° (0.2 mm) (lit.[80] 107°, 4.2 mm); ir (OH) 3360 cm^{-1}; mass spectrum (70 eV) m/e (rel intensity) 162 (26), 147 (100), 129 (47), 128 (16), 91 (16), 77 (16); nmr spectrum agreed with lit.[80] values.

1,1-Dimethylindene (60). To a 1-l. flask equipped with stirring bar, addition funnel, and Dean-Stark trap, were added 10 g of dried Amberlyst-15[65] and 300 ml of dry cyclohexane. The stirred mixture was brought to reflux. A 24-g (0.15 mol) sample of 59 in 50 ml of cyclohexane was added over a 20-min period. Reflux was continued for 30 min, the mixture was filtered, and cyclohexane was distilled from the filtrate to give 21 g of oil. Distillation gave 17.3 g (81%) of 60: bp 33° (0.2 mm) (lit.[80] 57°, 4.8 mm); mass spectrum (70 eV) m/e (rel intensity) 144 (52), 129 (100), 128 (47), 127 (20), 51 (14), 15 (11); nmr spectrum agreed with the published spectrum.[80]

An oxidation and isolation procedure identical to that described for the conversion of 6 to 58 gave:

5-tert-Butyl-3,3-dimethyl-1-indanone: mp 49-51°;(lit.[81] bp 180-2°); ir (C=O) 1712 cm^{-1}; nmr (CCl_4) 7.38, 7.31, (s, 2, ArH), 2.42 (s, 2, $-COCH_2-$), 1.40 (s, 6, gem-CH_3), 1.35 (s, 9, $-C(CH_3)_3$).

6-tert-Butyl-3,3-dimethyl-1-indanone: mp 50-1° (lit.[15] 51-51.8°); ir (C=O) 1720 cm^{-1}; nmr (CCl_4) δ 7.48 (m, 2, ArH), 7.30 (s, 1, ArH),

2.43 (s, 2, $-COCH_2-$), 1.39 (s, 6, gem-CH_3), 1.33 (s, 9, $-C(CH_3)_3$).

7-tert-Butyl-3,3-dimethyl-1-indanone: bp 75° (0.1 mm); ir (C=O) 1707 cm^{-1}; mass spectrum (70 eV) m/e (rel intensity) 216 (65), 201 (100), 174 (65), 173 (30), 159 (81), 115 (28); nmr (CCl_4) δ 7.40-7.10 (m, 3, ArH), 2.46 (s, 2, $-COCH_2-$), 1.41 (s, 9, $-C(CH_3)_3$), 1.36 (s, 6, gem-CH_3).

Anal. Calcd for $C_{15}H_{20}O$: C, 83.28; H, 9.32. Found: C, 83.05; H, 9.10.

3,3,7,7-Tetramethyl-s-hydrindacen-1-one (18). To a 2-l. flask equipped with magnetic stirring bar and heating mantle was placed 1 l. of acetic acid and 4 g (0.018 mol) of crystalline 7. The mixture was warmed and stirred until the hydrocarbon dissolved. The solution was cooled to 30°, 50 ml of 10% CrO_3 solution in acetic acid was added over 30 min, and stirring was continued 24 hr. Water (6 l.) was added with stirring and a pink solid separated from the diluted layers. This solid (2.75 g) was filtered out with a sintered-glass funnel. The filtrate was extracted with three 1-l. portions of ether and the ether solution, after drying ($MgSO_4$), and evaporation, gave 1.17 g of orange solid. This was combined with the solid isolated by filtration and the mixed crystals were recrystallized from petroleum ether[32] and sublimed at 75° (0.1 mm) to give 3.7 g (87%) of 18: mp 81-2°; ir (C=O) 1715 cm^{-1}; mass spectrum (70 eV) m/e (rel intensity) 228 (15), 214 (17), 213 (100), 171 (20), 129 (8), 128 (10); nmr (CCl_4) δ 7.28, 7.13 (s, 2, ArH), 2.92 (t, 2, $ArCH_2-$), 2.43 (s, 2, $-COCH_2-$), 1.95 (t, 2, $ArCH_2CH_2-$), 1.38, 1.28 (s, 12, gem-CH_3).

Anal. Calcd for $C_{16}H_{20}O$: C, 84.16; H, 8.83. Found: C, 84.30; H, 8.76.

A procedure similar to that used for preparation of 18 was used to prepare the following:

3,3,5,5-Tetramethyl-s-hydrindacen-1-one (19): mp 98-99°; ir (C=O) 1705 cm^{-1}; mass spectrum (70 eV) m/e (rel intensity) 228 (20), 214 (17), 213 (100), 171 (20), 129 (10), 128 (11); nmr (CCl_4) δ 7.39, 7.09 (s, 2, ArH), 2.93 (t, 2, $ArCH_2$-), 2.47 (s, 2, -$COCH_2$-), 1.97 (t, 2, $ArCH_2CH_2$-), 1.42, 1.30 (s, 12, gem-CH_3).

Anal. Calcd for $C_{16}H_{20}O$: C, 84.16; H, 8.83. Found: C, 84.28; H, 8.67.

3,3,4,5,5,8-Hexamethyl-s-hydrindacen-1-one (56): mp 186-8°; ir (C=O) 1710 cm^{-1}; mass spectrum (70 eV) m/e (rel intensity) 256 (30), 242 (19), 241 (100), 199 (11), 185 (26), 142 (7); nmr (CCl_4) δ 2.73 (t, 2, $ArCH_2$-), 2.43 (overlapping s, 5, $ArCH_3$ and -$COCH_2$-), 1.89 (t, 2, $ArCH_2CH_2$), 1.49, 1.36 (s, 12, gem-CH_3).

Anal. Calcd for $C_{18}H_{24}O$: C, 84.32; H, 9.44. Found: C, 84.30; H, 9.44.

3,3,6,6-Tetramethyl-as-hydrindacen-1-one: mp 60-61°; ir (C=O) 1709 cm^{-1}; mass spectrum (70 eV) m/e (rel intensity) 228 (29), 214 (17), 213 (100), 171 (12), 129 (10), 128 (12); nmr (CCl_4) δ 7.13 (s, 2, ArH), 3.12 (t, 2, $ArCH_2$-), 2.41 (s, 2, -$COCH_2$-), 1.96 (t, 2, $ArCH_2CH_2$-), 1.38, 1.24 (s, 12, gem-CH_3).

Anal. Calcd for $C_{16}H_{20}O$: C, 84.16; H, 8.83. Found: C, 83.99; H, 8.81.

The ketone 56 was prepared from previously undescribed 55: mp 135-6°; nmr (CCl_4) δ 2.62 (t, 4, $ArCH_2$-), 2.28, 2.03 (s, 6, $ArCH_3$), 1.82 (t, 4, $ArCH_2CH_2$-), 1.31 (s, 12, gem-CH_3). Upon oxidation, 55 gave 56 and a small amount of 57 which was separated by preparative glc[66c]

(250°, 50 cc/min). For 57: mp 265-7°; ir (C=O) 1705 cm^{-1}; mass spectrum 270 (59), 256 (20), 255 (100), 153 (6), 128 (16), 115 (6), nmr (CCl_4) δ 2.82, 2.58 (s, 6, $ArCH_3$), 2.53 (s, 4 $-COCH_2-$), 1.56 (s, 12, gem-CH_3).

Anal. Calcd for $C_{18}H_{26}$: C, 89.19; H, 10.81. Found: C, 89.29; H, 10.76.

Anal. Calcd for $C_{18}H_{22}O_2$: C, 79.96; H, 8.20. Found: C, 80.16; H, 8.17.

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VITA

Weldon Menno Harms

Candidate for the Degree of

Doctor of Philosophy

Thesis: CYCLIALKYLATION OF BENZENE WITH ISOPRENE

Major Field: Chemistry

Biographical:

Personal Data: Born in Hobart, Oklahoma, March 26, 1944, the son of Mr. and Mrs. Menno Harms

Education: Graduated from Cherokee High School, Cherokee, Oklahoma, in 1962; received the Bachelor of Science degree from Northwestern State College, Alva, Oklahoma, in May, 1967; completed requirements for the Doctor of Philosophy degree at Oklahoma State University in May, 1972.

Professional Experience: Undergraduate Laboratory Assistant, Northwestern State College, 1966-67; Graduate Teaching Assistant, Oklahoma State University, 1968-71.

Professional and Honorary Societies: American Chemical Society, Phi Lambda Upsilon, Blue Key.